Weapons Systems of the FUTURE

TOOLS OF THE TRADE FOR THE SCI-FI WRITER

BY LINK MILLER

Why you need this class

Writer's Perspective: If you have ANY military or weapons in your story, you must get the facts right or your credibility is shot.

No matter what you are writing or will eventually write about, you need a strong foundation and knowledge of weapons systems.

If you have a weapons scene without this basic foundation, your readers may catch you out on lack of veracity.

All information in this brief is from **UNCLASSIFIED** sources

Background

I am a 27 yr. veteran (retired Lt Colonel) of the US Marines.

I have served all over the US and the world. I am a trained expert in everything from hand weapons, assault helicopter operations, and Air Defense & Space Tactics. I was the USMC rep for non-lethal weapons development, a professional war gamer, and I spent my last 8 years on Air Force bases doing Space & Missile Defense.

Areas we will cover

- Near future (10-25 years)
- Far future (25+)
- Non-Lethal (NLW)
- DARPA (Defense Advanced Research Projects Agency)
- Air
- Sea
- Land
- Air
- Space
- Communications (good/bad)
- Reality VS Hollywood

Near Future

What is ‘near’ future as it applies to weapons?

The near future is a world which is imminently real – one of which we can have no definite knowledge, which exists only imaginatively and hypothetically, but which is nevertheless a world in which (or something like it) we may one day have to live, and towards which our present plans and ambitions must be directed.

The fears and hopes reflected in our images of the near future are real, however over pessimistic or over optimistic they may seem.

1 – 10 years (Think of how long it takes to field a new system)

Far future

What is the far future as it pertains to weapons?

- The far future tends to be associated with notions of ultimate destiny, and is dominated by metaphors of senescence; its images display a world irrevocably transfigured.

It is viewed from a detached viewpoint; the dominant mood is – paradoxically – one of nostalgia, because the far future, like the dead past, can be entered only imaginatively, and has meaning only in terms of its emotional resonances.

- 10 - 25 + years

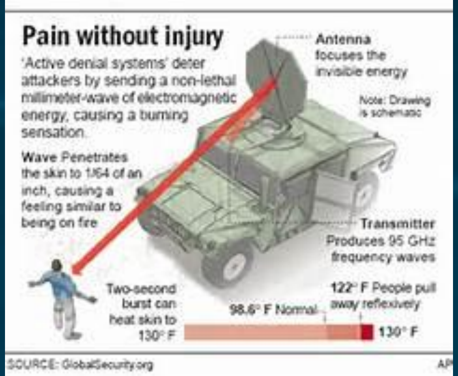
DARPA

(Defense Advanced Research Projects Agency)

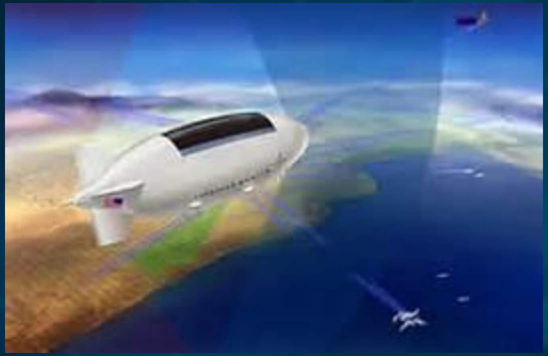
The Defense Advanced Research Projects Agency is an agency of the U.S. Department of Defense responsible for the development of emerging technologies for use by the military. DARPA was created in February 1958 as the Advanced Research Projects Agency by President Dwight D. Eisenhower.

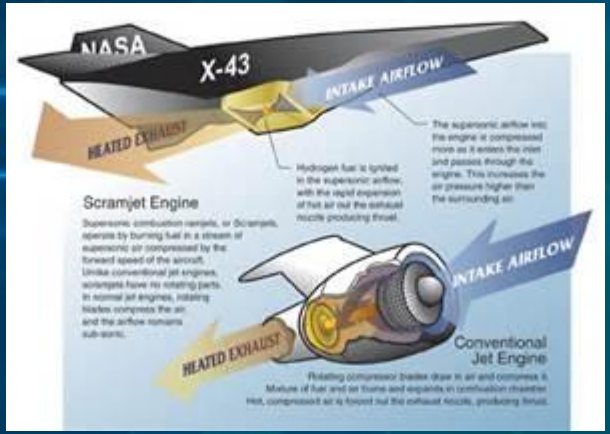
Non-Lethal Weapons

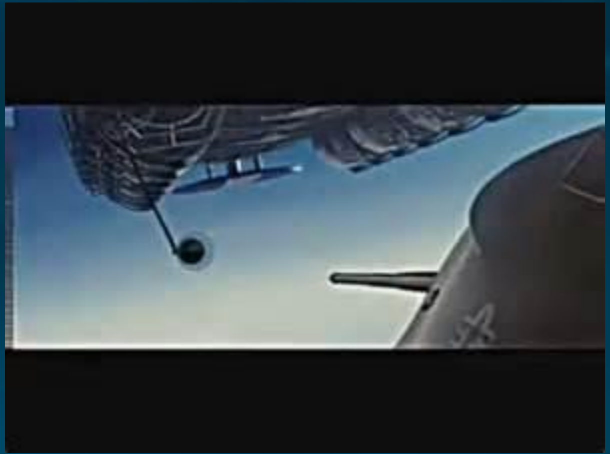
- AKA known as less-than-lethal
- Active Denial System (The Fentonizer)
- Anti-traction material (Bad example-sticky foam)
- TASER Shotgun
- PHASR (Yes, real phasers… set on stun, duh)
- Incapacitating Flashlight
- Speech Jammer



AIR – small, medium, and large







Fast Lightweight Autonomy (FLA)

Small, fast, agile unmanned vehicles that can operate in tight spaces indoors was recently tested sensor-laden quadcopters that managed to avoid obstacles while hitting their target speed on 20 meters per second (about 45 miles per hour).

The goal behind FLA is to give dismounted soldiers a view inside buildings, especially in urban areas, and do it with a minimum of involvement by drone operators. FLA is working to develop algorithms that will allow small drones to operate independently, gathering images and data inside a building without an operator, who might have other things to do, having to control their every movement.

Aurora Excalibur

The Aurora Excalibur is an unmanned aircraft that operates with a vertical take off and landing. It can reach speeds of 460 miles per hour and carry cargo or onboard missiles. The aircraft is operated by remote control.

The Excalibur was **successfully tested in June of 2009.**

VTOL X-Plane

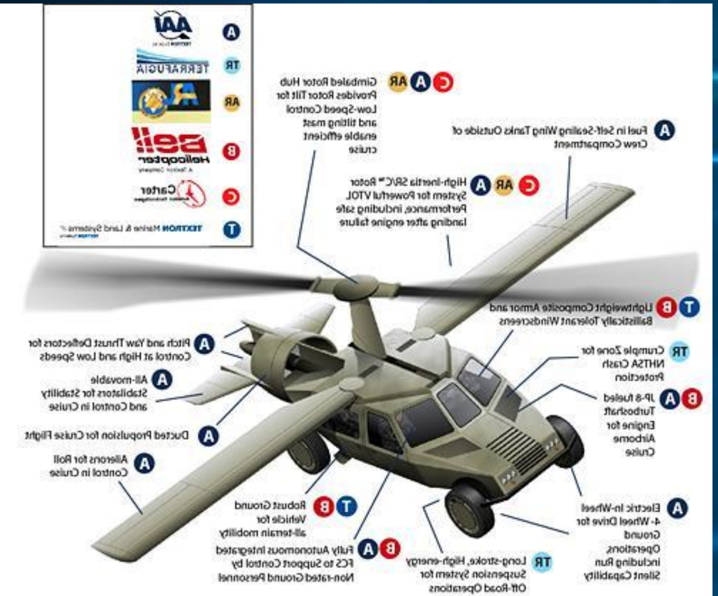
Through a hybrid of fixed-wing and rotary-wing technologies, DARPA is looking at a plane that can efficiently take off and hover like a helicopter and fly at high-speeds like an aircraft. This project is currently exploring unmanned aircraft, but the technology can apply to manned aircraft as well.

From this…	to this

FLYING CARS (It's about time)

DARPA's Transformer TX 'flying Humvee' project

The Transformer TX project calls for four-man vehicle that drives like a jeep and then takes off to avoid roadside bombs (or impress the ladies).



Actually, why bother driving at all?

FUTURE VTOL

The traditional problem with VTOL aircraft has been the tremendous complexity involved in having to transition from horizontal flight to vertical flight and the incredible downwash forces.

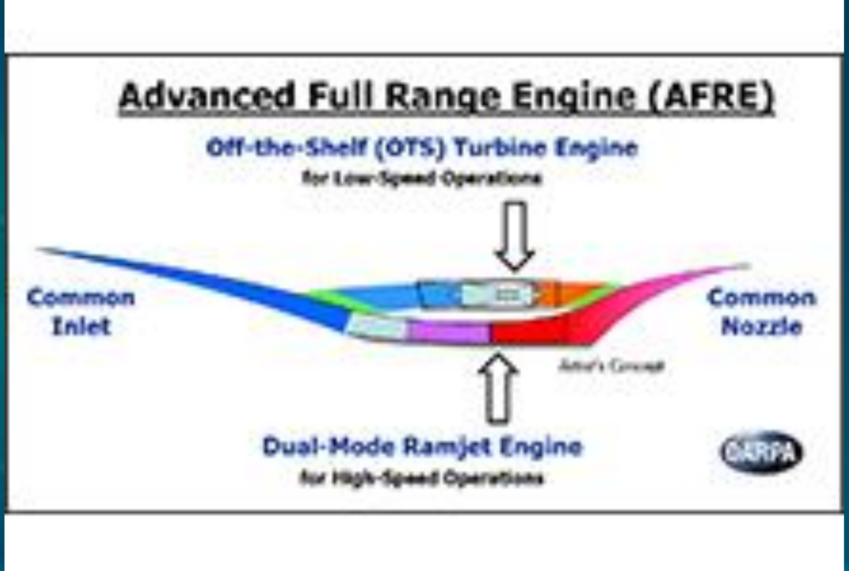
FYI Fan-in-Wing were pretty much the least successful of all the VTOL approaches attempted by NASA and the DOD over the past 60 years.



Advanced Full Range Engine (AFRE) Program

Hybrid Propulsion System is paving the way to routine, reusable hypersonic flight.

In the decades-long quest to develop reusable aircraft that can reach hypersonic speeds—Mach 5 (approximately 3,300 miles per hour) and above—engineers have grappled with two intertwined, seemingly intractable challenges: The top speed of traditional jet-turbine engines maxes out at roughly Mach 2.5, while hypersonic engines such as scramjets cannot provide effective thrust at speeds much below Mach 3.5.



HAA (High Altitude Airships)

An untethered, unmanned lighter-than-air vehicle that will operate above the jet stream in a geostationary position to deliver persistent station keeping as a surveillance platform, telecommunications relay, or a weather observer.

Unmanned, powered airship that can maintain a relatively geostationary position at 70,000 feet. Lift is provided by helium that is contained in its envelope. Differential thrust, electric-powered props control the pitch and roll and keep it in position. With the advent of thin-film photovoltaic solar cells (capable of producing voltage when exposed to radiant light), commercially available fuel cells, and lightweight/high-strength fabrics.

High Energy Liquid Laser Area Defense System (HELLADS)

The Pentagon's Defense Advanced Research Projects Agency (DARPA) is developing the future of lasers weapons known as High Energy Liquid Laser Area Defense System. The goal of this laser system is to be compact enough to fit on board of a tactical aircraft without affecting mission performance. The lasers would be powerful enough to shoot down rockets, missiles, and artillery shells.

LASERS

US Army will have laser weapons by 2023 as research bosses say killer technology is "very close."

Initial trials of laser weapon revealed "unprecedented power" of system

First demonstrations expected to take place in 2020

Team now building full powered unit for lab tests

Land

Men, armor, and weapons

Robots & drones

Mech (walkers, rollers, and things that go BOOM!)

Kinetic & non-kinetic weapons

New Medical Unit - drones and bio readers

DARPA Jetpack

Gives soldiers speed of Flash...well, not really

Arizona State University is developing a jetpack, but rather than help the wearer fly, it is designed to help them run faster. The 4MM, or 4 Minute Mile, project is being funded by DARPA.

It aims to help every wearer, eventually every soldier, be able to easily run a four-minute mile without exerting too much energy.

Testers have shaved 30 seconds off their time even while wearing the 11 pound jet pack.

Body Armor

Clothing worn by military and police personnel to protect against gunfire or shrapnel.

BATTLE SUITS (Starship Trooper Style)

Tactical Assault Light Operator Suit (TALOS) is the Main Powered Suit of the Mobile Infantry (MI).

There are several hard points on the armor, allowing it able to be attached with various optional equipment and weapons, such as a small missile launcher or a combat knife. On each elbow, there is a large hard point, which is made per standards of a tank and a fighter jet. Weapons can be place on the rack on the back. Two jump jets are mounted in the lower back of the armor. They will open when in use.

Each helmet has a searchlight mount on its left and a infrared camera on the right side. There are four camera-eyes on the visor that provide the image of outside, displayed on the other side of the visor. There is a HUD system inside the helmet.

SIPES - Soldier Integrated Precision Effects Systems

Along with the ability to fire new lightweight telescoped ammunition, and a secondary effects module that adds either a three-round 40mm grenade launcher or a 12-gauge shotgun, there is also a NATO-standard power and data bus to allow the attachment of smart accessories, such as electro-optical sights and position sensors that connect to command and control networks.

EXACTO – Laser Guided Bullet

The EXACTO 50-caliber round is claimed to be the first ever guided small-caliber bullet. The maneuverable projectile uses a real-time optical guidance system to change its path mid-flight and home in on a target, potentially overcoming adverse weather and hostile conditions to improve sniper accuracy (2 miles).

LAND - Weapons

XM-25 Grenade Launcher

The XM-25 is capable of firing up to 25 grenades at any distance that can be predetermined and programmed by the user.

This new weapon combines the capabilities of both a gun and a computer in one. It is rumored that five XM-25 guns **were used in Afghanistan.**

Invisibility (E-Camouflage)

Heated via electrical stimulation, the sharp temperature gradient between the cloak and the surrounding area causes a steep temperature gradient that bends light away from the wearer.

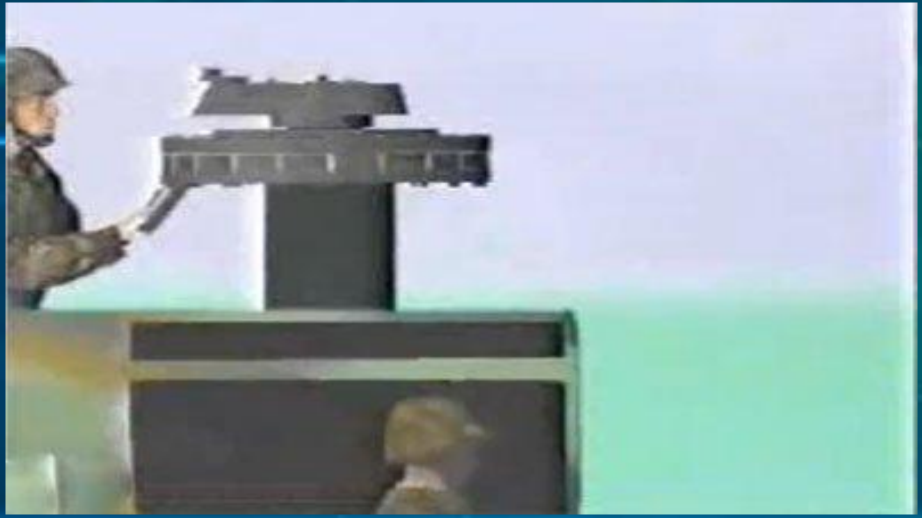
Metamaterials: tiny structures that are smaller than the wavelength of light. If properly constructed, they guide rays of light around an object -- much like a rock diverting water in a stream.

Projection skin – projects what is behind subject onto front.

DREAD Silent Weapon System

The DREAD Silent Weapon System has the ability to shoot 120,000 rounds per minute.

The gun runs fully on electrical energy, not gunpowder, which means no recoil, no sound, and no heat. **Debut date unknown.**



Ground X Technology (GXV-T)

Today's ground-based armored fighting vehicles are better protected than ever, but face a constantly evolving threat: weapons increasingly effective at piercing armor. While adding more armor has provided incremental increases in protection, it has also hobbled vehicle speed and mobility and ballooned development and deployment costs.

To help reverse this trend, DARPA's Ground X-Vehicle Technology (GXV-T) program, recently awarded contracts to eight organizations, promises nimbler, faster, smarter armored ground vehicles.

MEDEVAC

- Retrieve
- Scan
- EMT
- Dustoff

Sea

- Surface vessels
- Drones
- Rail guns
- Lasers
- Stealth



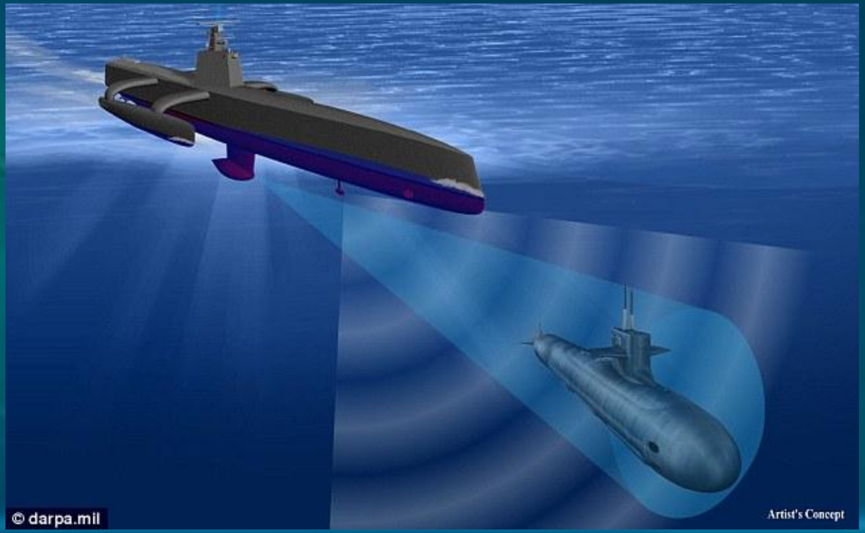

SEA -The Free Electron Laser

The Navy is in the process of designing another laser system to shoot down rockets and missiles that may attack its ships. There are endless uses for the laser when it's not shooting down enemy fire, such as a tracker, sensor, information exchange, and target designation among others.

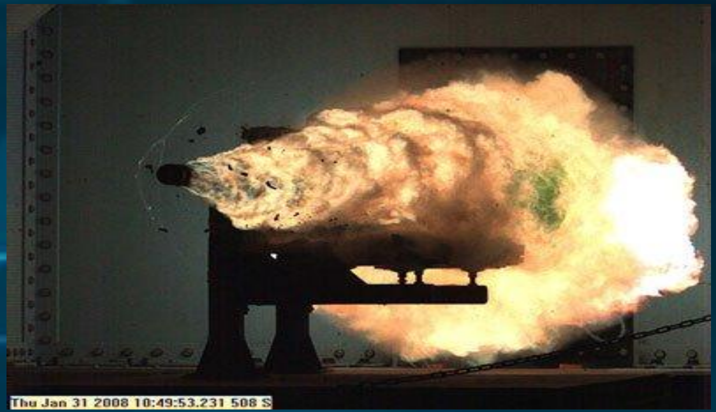
Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV)

The first 132-foot long ship, to be used for counter-mine missions, reconnaissance and resupply, took to the water on April 7th. The Anti-Submarine Warfare The ACTUV will be able to operate for several months at a time scouring the seas and coastal areas for silent, diesel powered enemy submarines.

The test boat was able to tail a target boat at 1 km distance, something military bosses say is a major step forward.

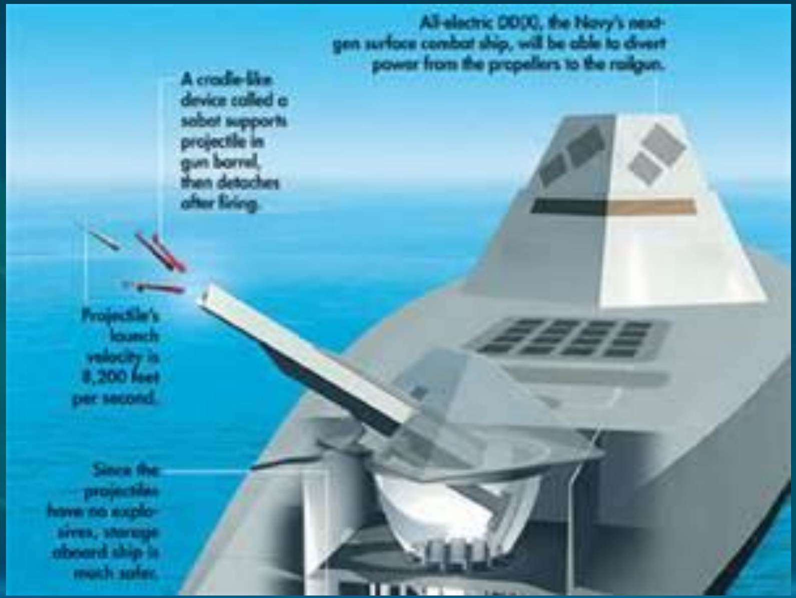


Land & Sea - Electromagnetic Rail Guns



EM rail gun launchers use a magnetic field rather than chemical propellants (e.g., gunpowder or fuel) to thrust a projectile at long range and at velocities of 4,500 mph to 5,600 mph, seven times the speed of sound.

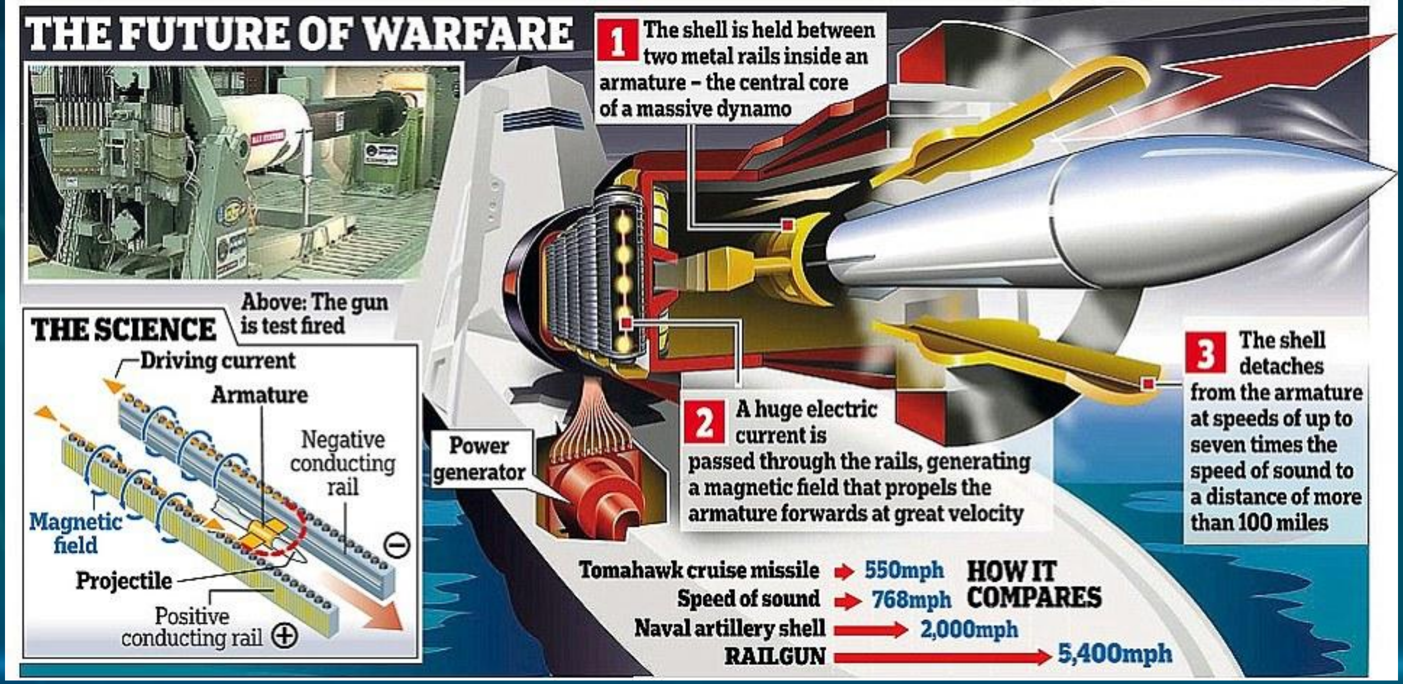
A perfected version of the gun is expected to be ready by **2025.**



RAIL GUNS (how they work)

A radical new weapon that can fire a shell at seven times the speed of sound could be used by the Navy as soon as 2018. Described as 'Star Wars technology' by researchers, the rail gun can fire a shell weighing 10kg at up to 5,400mph over 100 miles. It does this with such force and accuracy it penetrates three concrete walls or six half-inch thick steel plates.

Development of a futuristic weapon is going well enough that a Navy admiral wants to skip an at-sea prototype in favor of installing an operational unit aboard one of its new Zumwalt-class destroyers.



Space… the final frontier, especially for combat

- An extremely harsh environment
- Surveillance, communications systems
- Weapons: kinetic and non-kinetic

If you are writing in the far future 100+ years, feel free to have phasers, shields, and warp drive otherwise physics still apply

SPACE

Micro-satellites

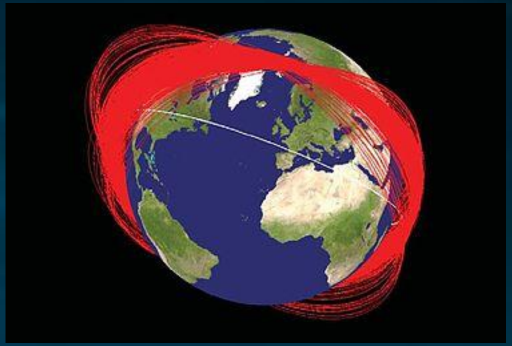
EMPs

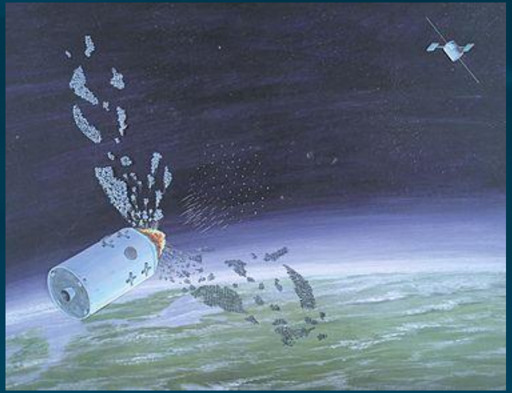
Lasers (Beams not Bolts)

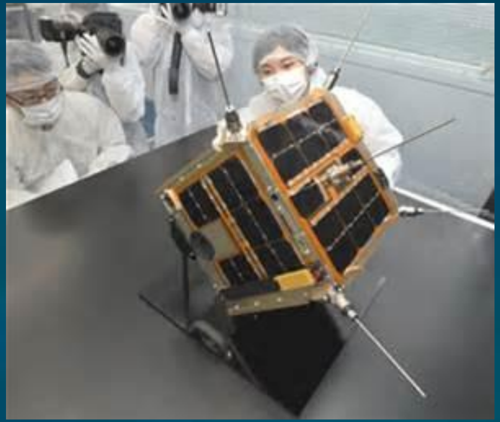
ASATs (2 types: orbital vs direct ascent)

Rail Guns (The real rods from the gods)

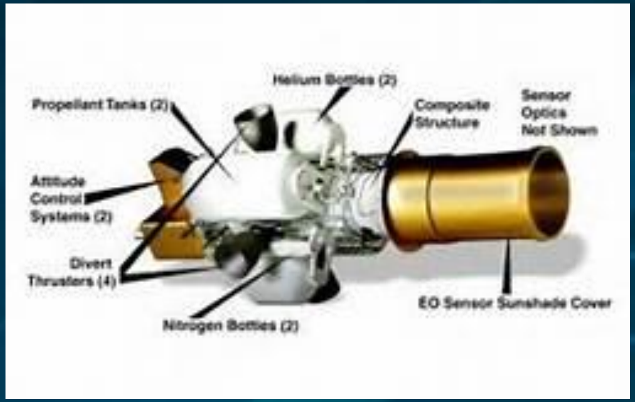
Dog Fights (Pac Man vs Top Gun)







Space



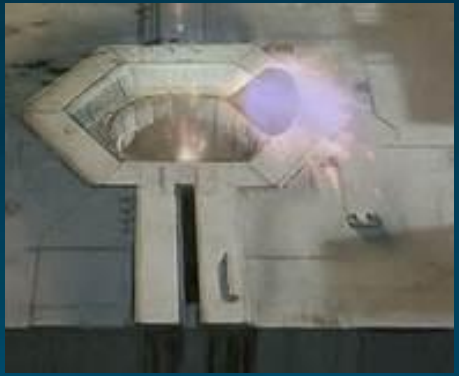
Kinetic vs non-kinetic

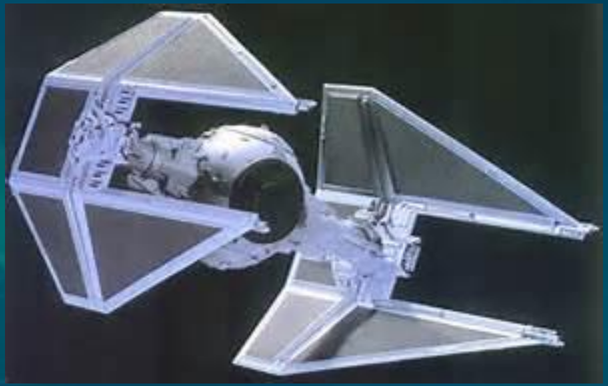
Today – KKV, Anti-satellite missiles

Tomorrow – lasers, particle beam

Future – phasers, disruptors, plasma cannons, photon (or proton) torpedoes,

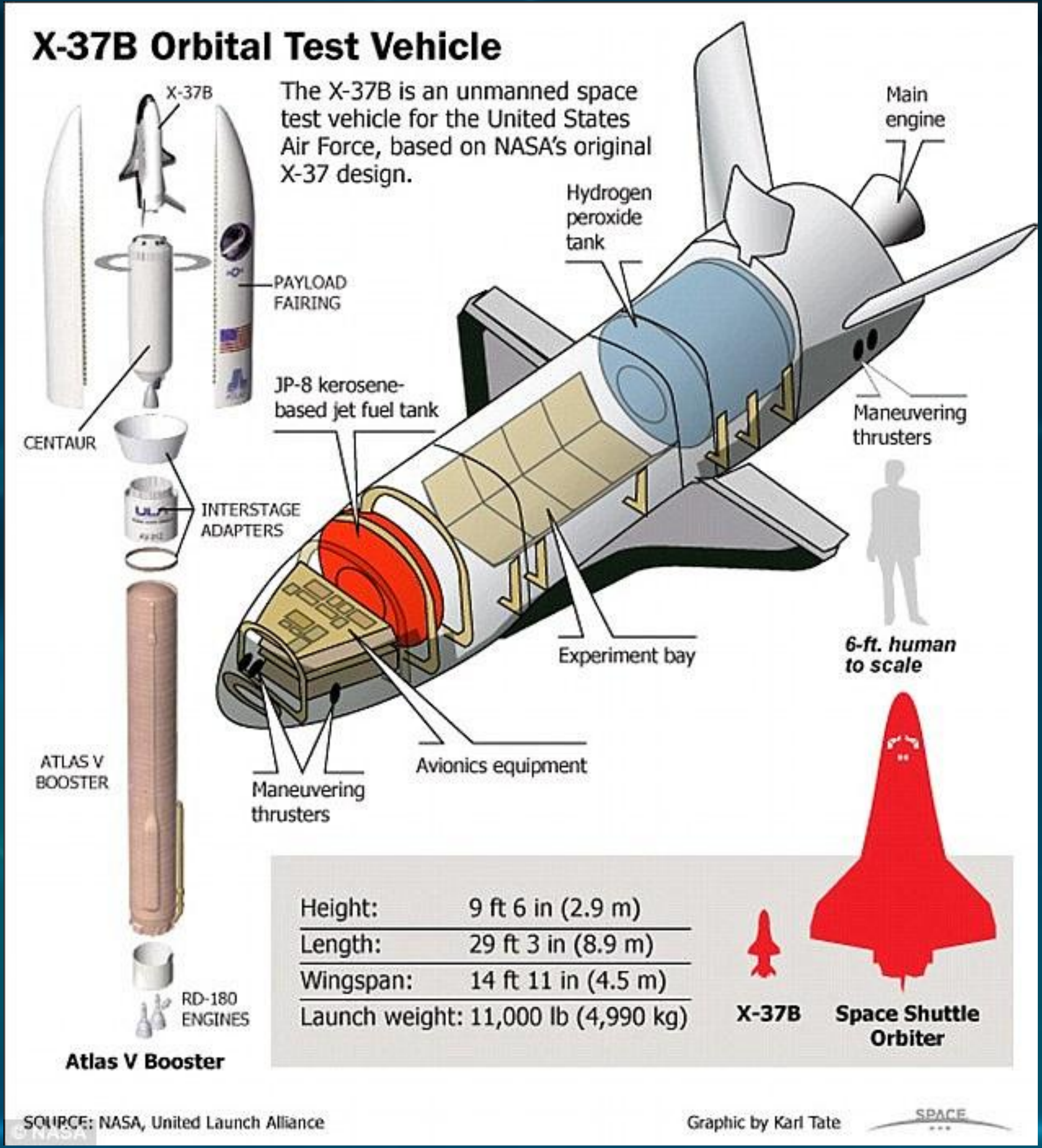
Remember, physics still apply. And there are no aerodynamics in space.





X-37B

Like a shuttle, X-37B is blasted into orbit by a rocket. However, it lands using a runway like a normal aircraft. The X-37B is too small to carry people onboard, but does have a cargo bay similar to that of a pickup truck, which is just large enough to carry a small satellite



XS-1(Experimental Spaceplane 1)

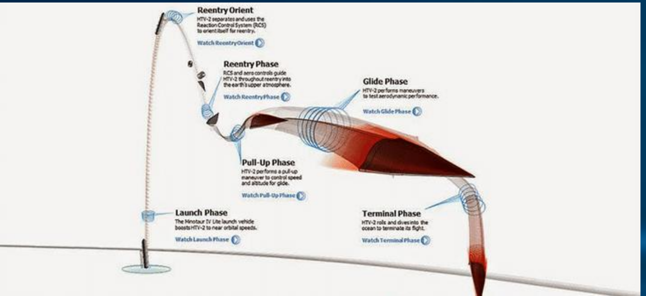
DARPA created its Experimental Spaceplane (XS-1) program with the major goal to reuse the spacecraft frequently, with a proposed launch rate of 10 missions in just 10 days.

The XS-1 is envisioned to heft payloads for less than $5 million a flight, each weighing between 3,000 and 5,000 lbs. (1,360 to 2,267 kilograms). The aircraft-like craft is also supposed to fly faster than Mach 10, or 10 times the speed of sound.

Hypersonic Cruise Missiles

After the terrorist attacks of September 11th 2001, American officials decided that they needed to obtain a “prompt global strike” capability to deliver superfast or “hypersonic” unmanned vehicles that can strike quickly by flying through the atmosphere, and cannot be mistaken for a nuclear missile.

The US is working on two kinds of hypersonic missiles. One is a boost glide system that rides a rocket into space, then reenters the atmosphere and glides to its target at up to 14,000 miles per hour. The other is an air-breathing missile, a close cousin to the ramjet, that scoops up oxygen as it flies a flatter, Mach-10 path to its destination.

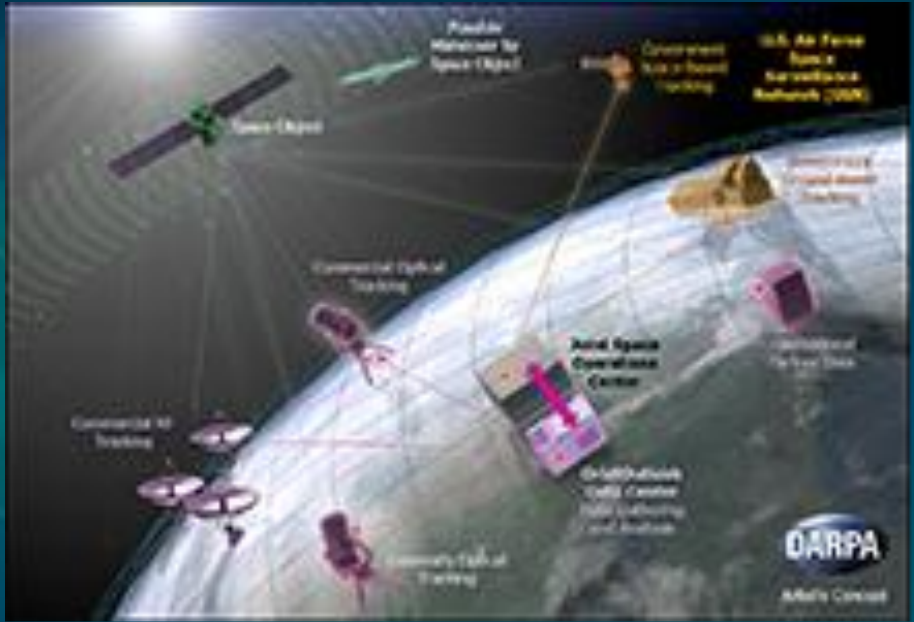


Orbital Outlook

Orbital Outlook integrates the largest and most diverse network of space sensors ever to help avoid collisions in space.

More than 500,000 pieces of manmade space debris—including spent rocket stages, defunct satellites, and fragments as small as flecks of paint—currently hurtle around the Earth at roughly 17,000 mph.

At those speeds, impacts involving even the smallest of those items can damage satellites and spawn chain reactions of collisions, increasing the amount of orbital flotsam and creating "minefields" in space that can remain impassable for centuries.



Missile Defense

The Missile Defense Agency's (MDA) mission is to develop, test, and field an integrated, layered, ballistic missile defense system (BMDS) to defend the United States, its deployed forces, allies, and friends against all ranges of enemy ballistic missiles in all phases of flight.

Space

Communications

In the movie *Contact* – radio signal (TV) took how long?

Star Trek (TOS) – message/answer from Star Fleet always came too late.

Faster Than Light Travel (FTL)

Mind – Linking?

Distant (Far) Future

Star Trek vs. *Star Wars*

Physics still apply (gravity, Newton, power, material degradation)

Not much chance without warp drive or a star gate

What about that whole time/space differential?

And how are you going to communicate?

Time, Space, Thought

Who knows where we will be in 100 years…
but watch out for SkyNet.

Reality Vs. Hollywood

So much shown in movies and on TV is rubbish.

Think physics, think practically, think logically

Minority Report

VS

DARPA – real time cmd & control

BOLT (Broad Operational Language Translation)

QUESTIONS?

Contact me:

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Yes, AOL… it's easy to remember

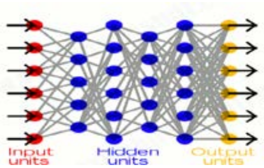
Explainable Artificial Intelligence (XAI)

David Gunning

DARPA/I2O

Explainable AI – What Are We Trying To Do?

AI System



Watson

AlphaGo

Sensemaking

Operations

User

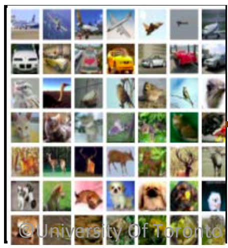
- We are entering a new age of AI applications
- Machine learning is the core technology
- Machine learning models are opaque, non-intuitive, and difficult for people to understand

- Why did you do that?
- Why not something else?
- When do you succeed?
- When do you fail?
- When can I trust you?
- How do I correct an error?

Dramatic success in machine learning has led to an explosion of AI applications. Researchers have developed new AI capabilities for a wide variety of tasks. Continued advances promise to produce autonomous systems that will perceive, learn, decide, and act on their own. However, the effectiveness of these systems will be limited by the machine's inability to explain its thoughts and actions to human users. Explainable AI will be essential, if users are to understand, trust, and effectively manage this emerging generation of artificially intelligent partners.

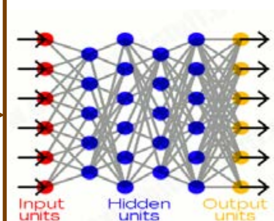
Explainable AI – What Are We Trying To Do?

Today



Training Data

Learning Process



Learned Function

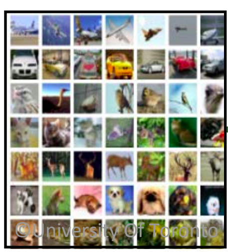
This is a cat
(p = .93)

Output

User with a Task

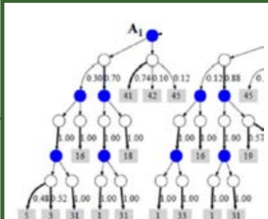
- Why did you do that?
- Why not something else?
- When do you succeed?
- When do you fail?
- When can I trust you?
- How do I correct an error?

Tomorrow



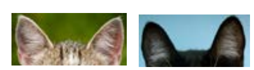
Training Data

New Learning Process



Explainable Model

This is a cat:
- It has fur, whiskers, and claws.
- It has this feature:



Explanation Interface

User with a Task

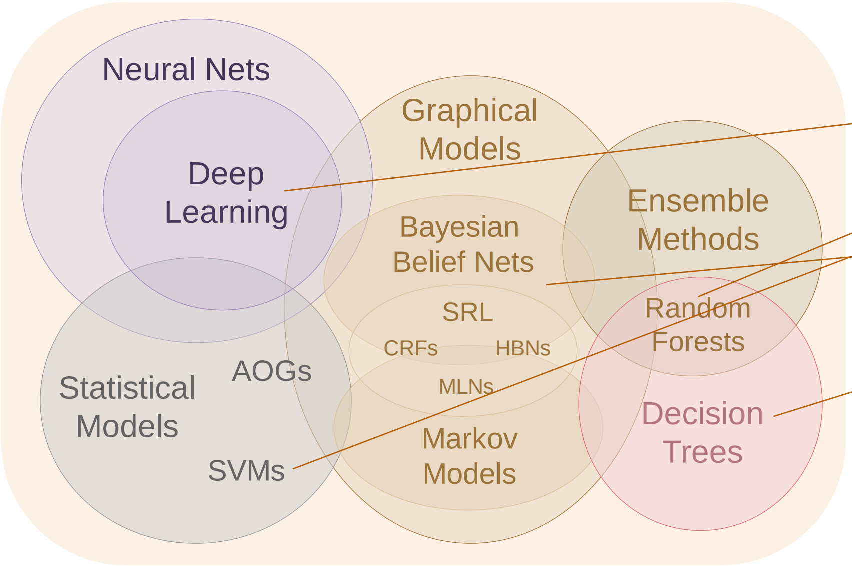
- I understand why
- I understand why not
- I know when you'll succeed
- I know when you'll fail
- I know when to trust you
- I know why you erred

Explainable AI – Performance vs. Explainability

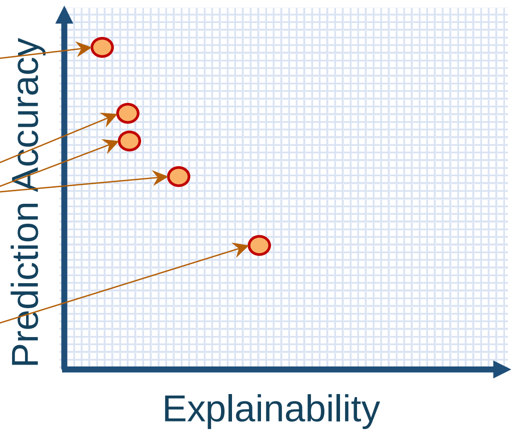
New Approach

Create a suite of machine learning techniques that produce more explainable models, while maintaining a high level of learning performance

Learning Techniques (today)



Explainability (notional)



Explainable AI – Performance vs. Explainability

New Approach

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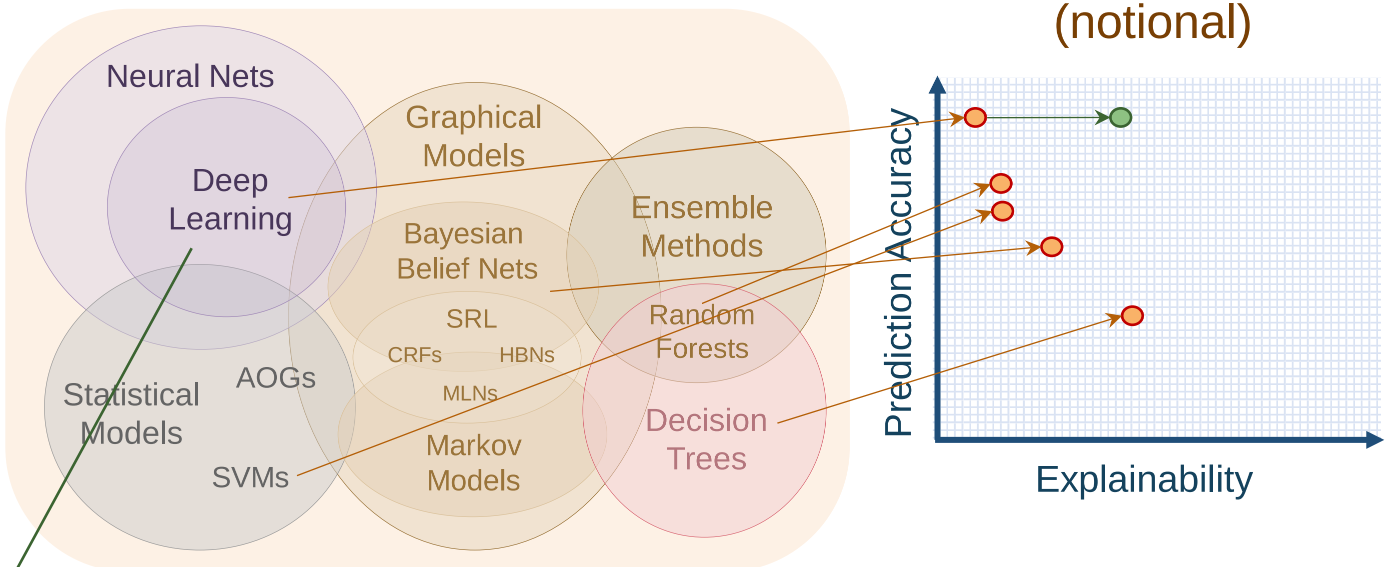
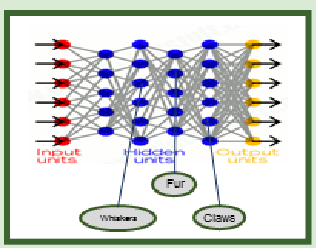
Learning Techniques (today)

Explainability (notional)



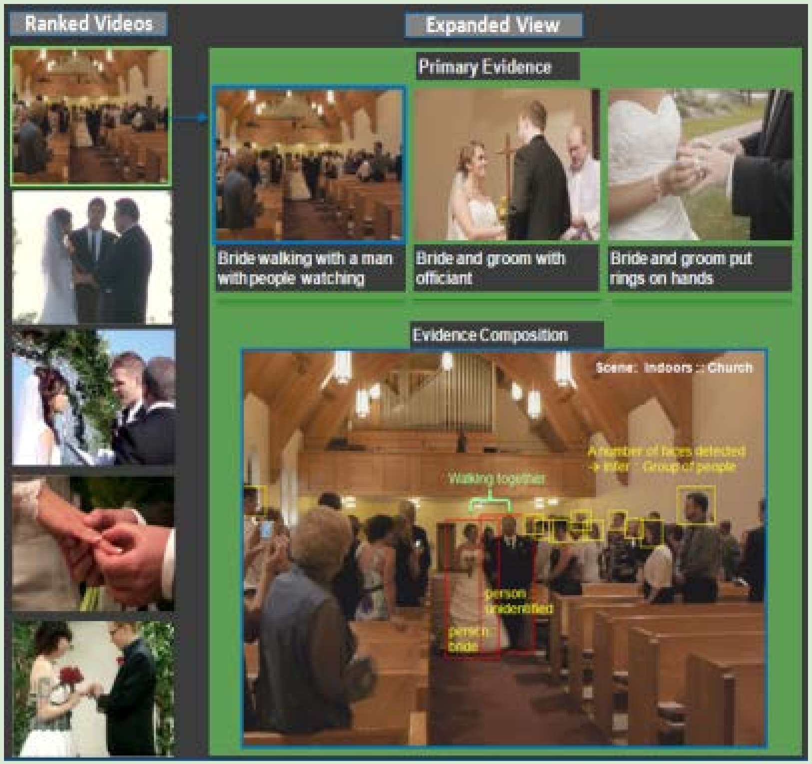


Deep Explanation

Modified deep learning techniques to learn explainable features

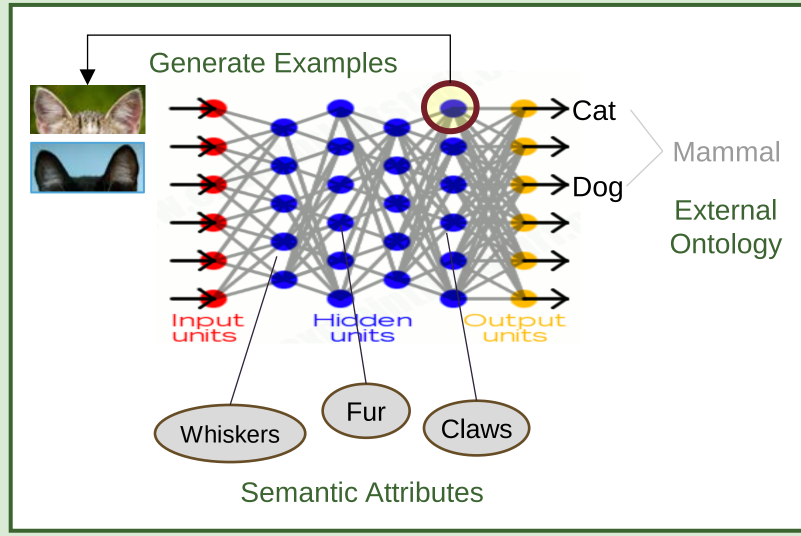
Learning Deep Explanations

Multimedia Event Recounting



- This illustrates and example of event recounting.
- The system classified this video as a wedding.
- The frames above show its evidence for the wedding classification

Learning Semantic Associations

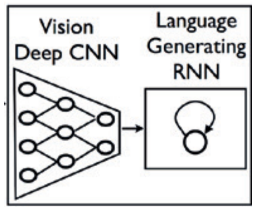


- Train the net to associate semantic attributes with hidden layer nodes
- Train the net to associate labelled nodes with known ontologies
- Generate examples of prominent but unlabeled nodes to discover semantic labels
- Generate clusters of examples from prominent nodes
- Identify the best architectures, parameters, and training sequences to learn the most interpretable models

Cheng, H., et al. (2014) SRI-Sarnoff AURORA at TRECVID 2014: Multimedia Event Detection and Recounting. http://www-nlpir.nist.gov/projects/tvpubs/tv14.papers/sri_aurora.pdf

Learning To Generate Explanations

Generating Image Captions

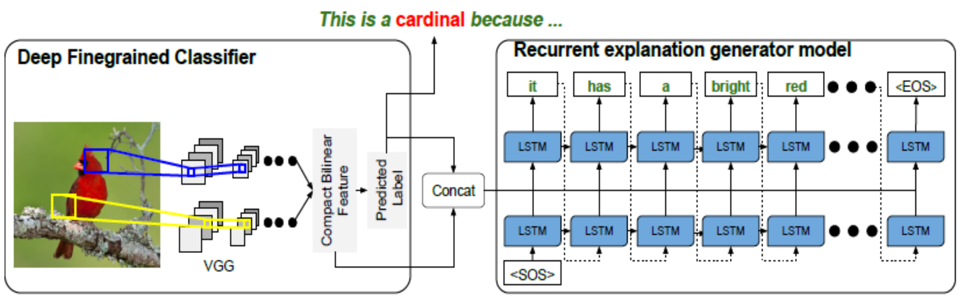


A group of people shopping at an outdoor market

There are many vegetables at the fruit stand

- A CNN is trained to recognize objects in images
- A language generating RNN is trained to translate features of the CNN into words and captions.

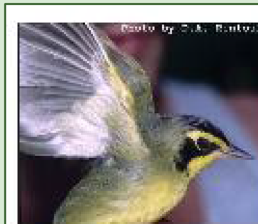
Generating Visual Explanations



Researchers at UC Berkeley have recently extended this idea to generate explanations of bird classifications. The system learns to:

- Classify bird species with 85% accuracy
- Associate *image descriptions* (discriminative features of the image) with *class definitions* (image-independent discriminative features of the class)

Example Explanations



This is a Kentucky warbler because this is a yellow bird with a black cheek patch and a black crown.

This is a pied billed grebe because this is a brown bird with a long neck and a large beak.

Limitations

- Limited (indirect at best) explanation of internal logic
- Limited utility for understanding classification errors

Hendricks, L.A, Akata, Z., Rohrbach, M., Donahue, J., Schiele, B., and Darrell, T. (2016). Generating Visual Explanations, arXiv:1603.08507v1 [cs.CV] 28 Mar 2016

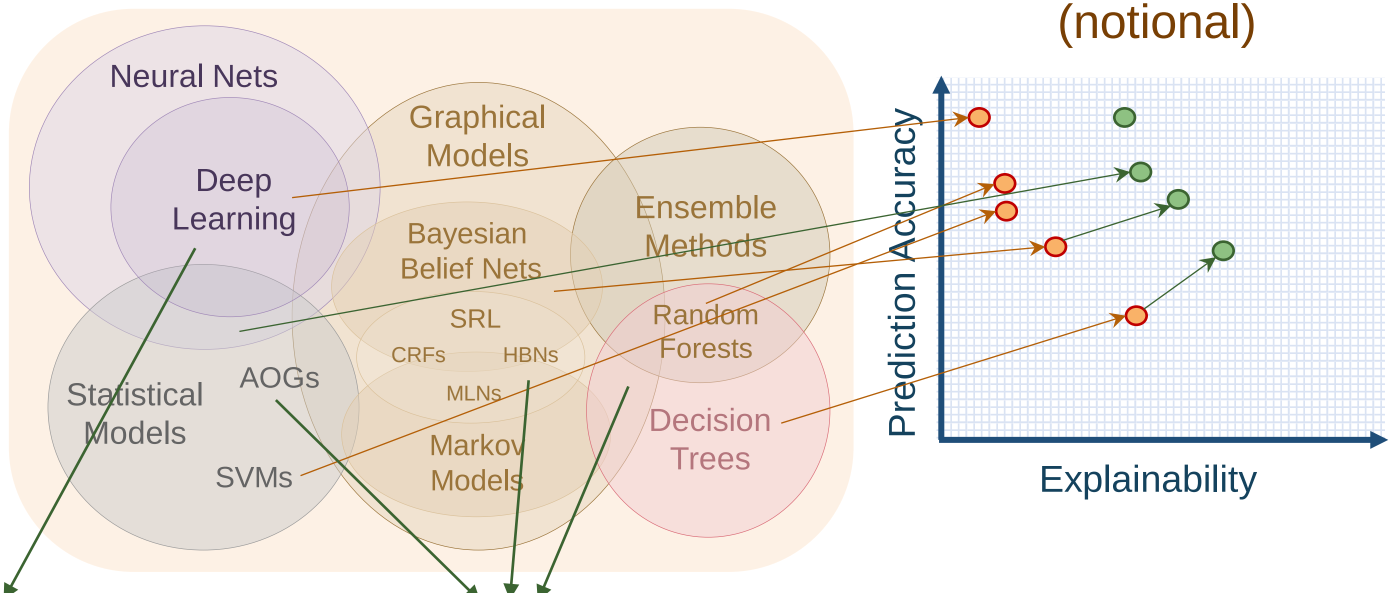
Explainable AI – Performance vs. Explainability

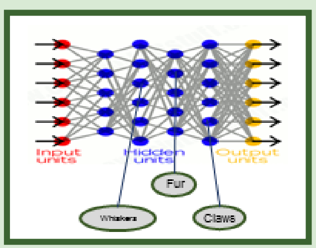
New Approach

Create a suite of machine learning techniques that produce more explainable models, while maintaining a high level of learning performance

Learning Techniques (today)

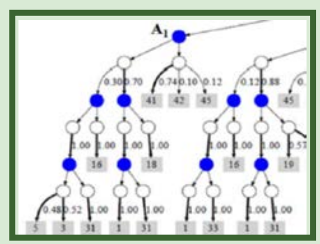
Explainability (notional)





Deep Explanation

Modified deep learning techniques to learn explainable features

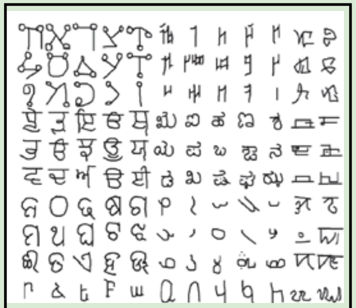


Interpretable Models

Techniques to learn more structured, interpretable, causal models

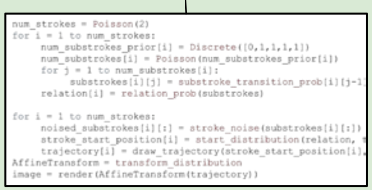
Learning More Interpretable Models

Training Data
1623 Characters

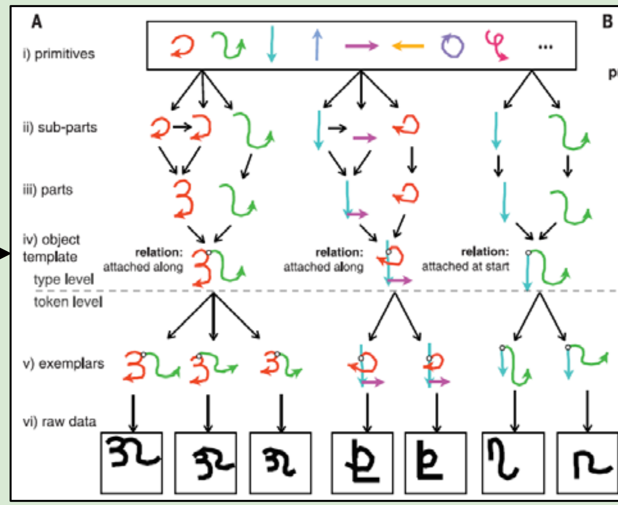


Concept Learning Through Probabilistic Program Induction

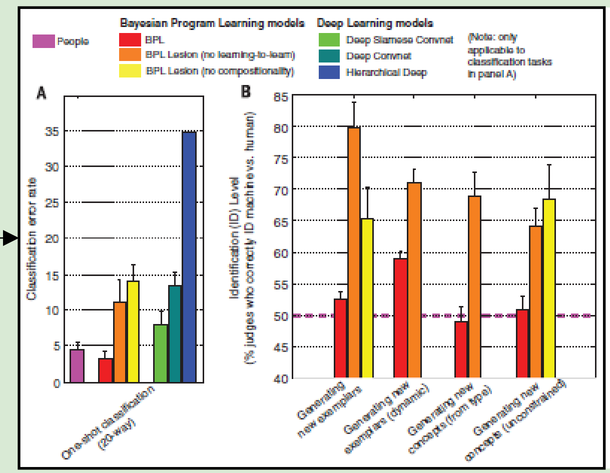
Bayesian Program Learning



Seed Model
A simple Probabilistic Program that describes the parameters of character generation



Generative Model
Recognizes characters by generating an explanation of how a new test character might be created (i.e., the most probable sequence of strokes that would create that character)

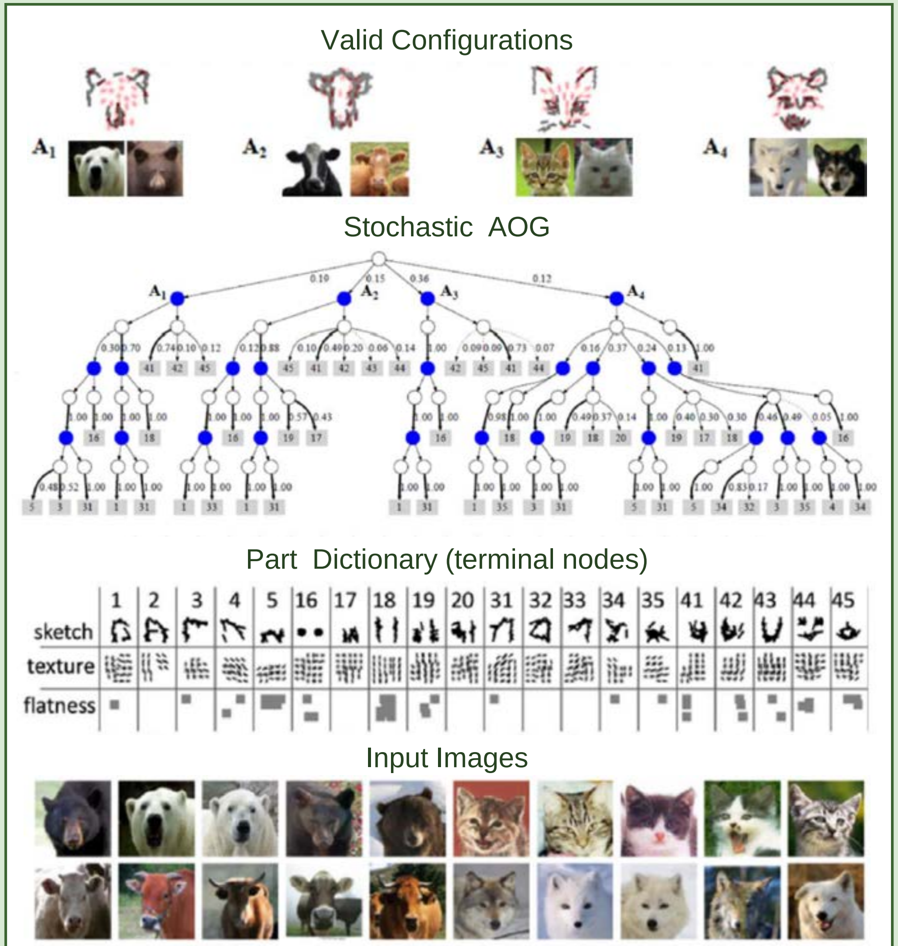


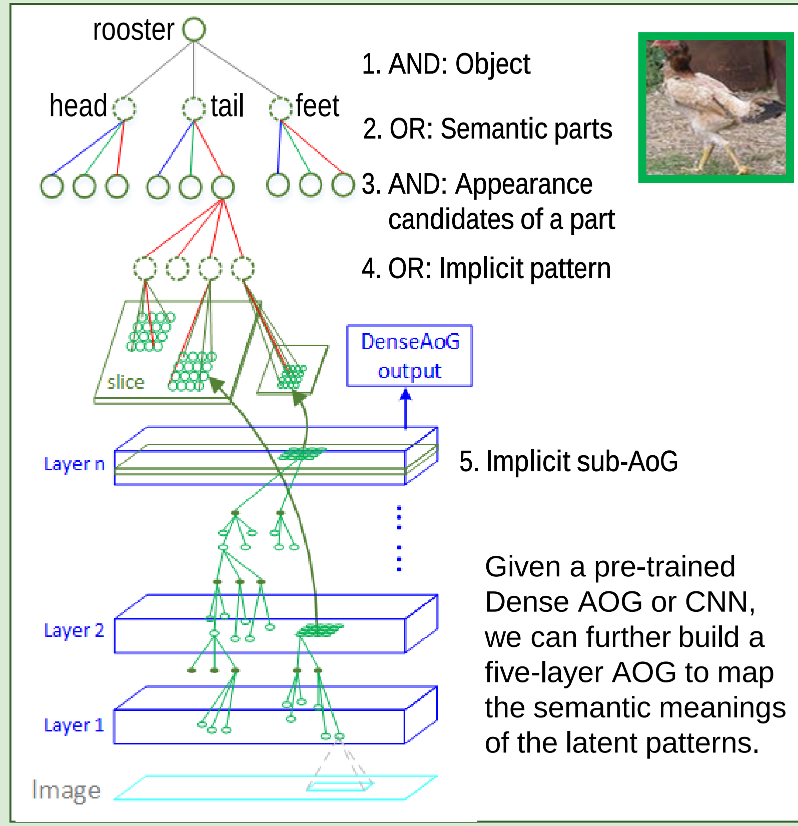
Performance
This model matches human performance and out performs deep learning

Lake, B.H., Salakhutdinov, R., & Tenenbaum, J.B. (2015). Human-level concept learning through probabilistic program induction. *Science.* VOL 350, 1332-1338.

Learning More Interpretable Models

Stochastic And-Or-Graphs (AOG)





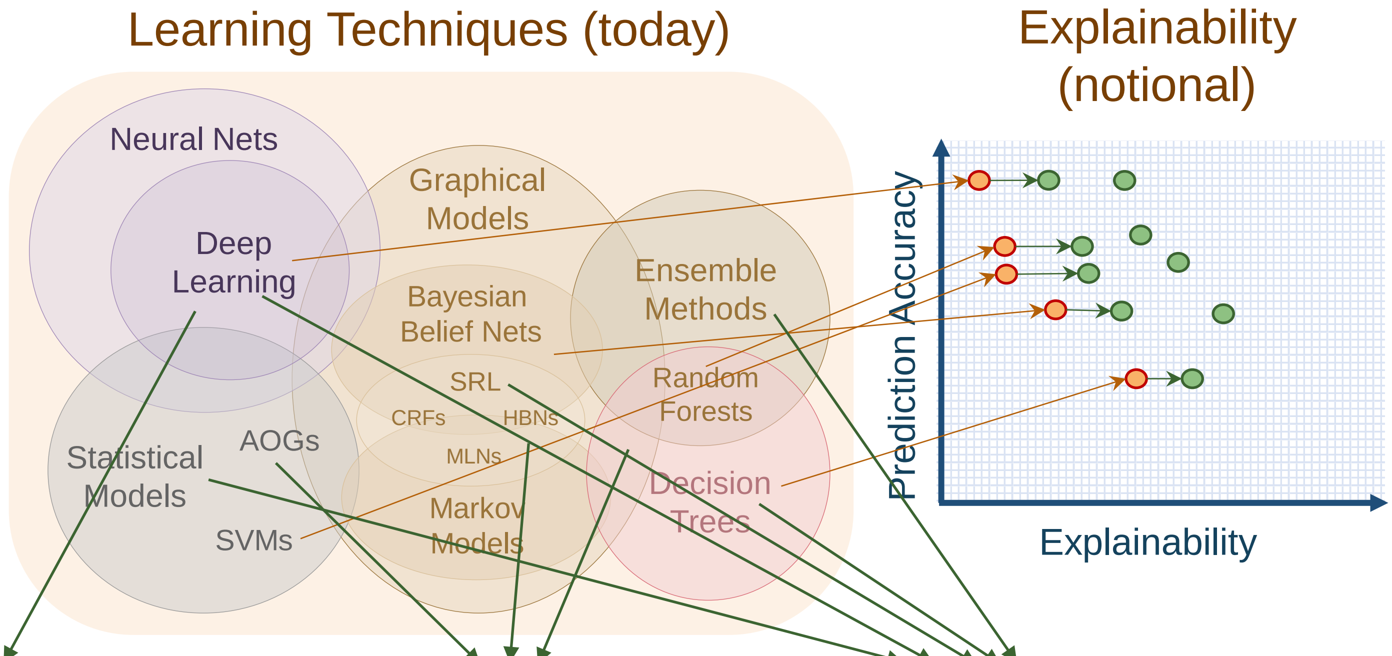
$$L(\theta) = \frac{1}{M}\sum_{m=1}^{M} \underbrace{\log P(I_m, \theta)}_{\text{generative}} + \underbrace{L(pg_m^*, \hat{pg}_m)}_{\text{discriminative}}$$

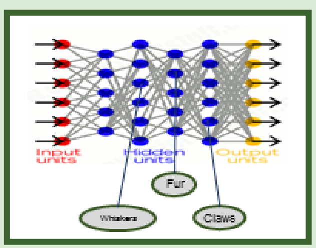
Si, Z. and Zhu, S. (2013). Learning AND-OR Templates for Object Recognition and Detection. *IEEE Transactions On Pattern Analysis and Machine Intelligence*. Vol. 35 No. 9, 2189-2205.

Explainable AI – Performance vs. Explainability

New Approach

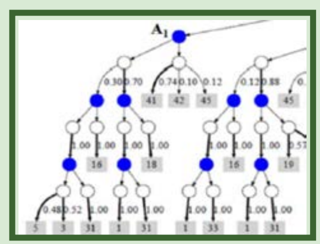
Create a suite of machine learning techniques that produce more explainable models, while maintaining a high level of learning performance





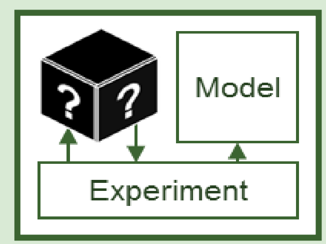
Deep Explanation

Modified deep learning techniques to learn explainable features



Interpretable Models

Techniques to learn more structured, interpretable, causal models



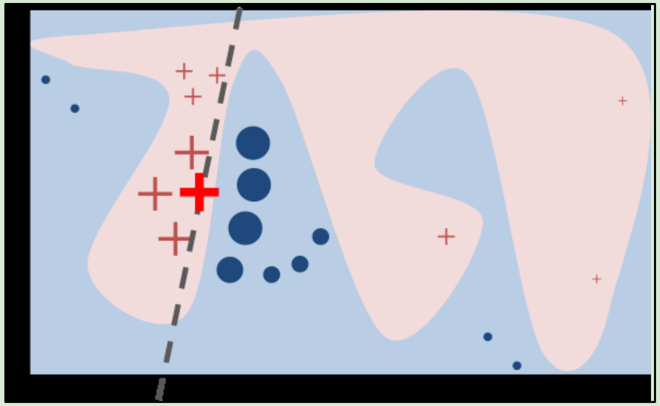
Model Induction

Techniques to infer an explainable model from any model as a black box

Model Induction

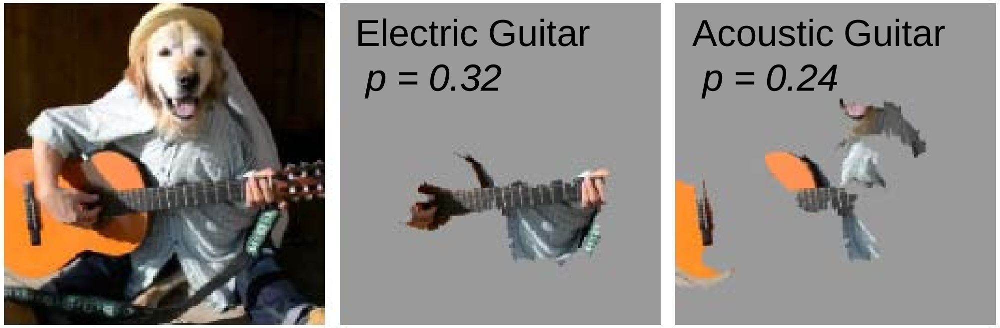
Local Interpretable Model-agnostic Explanations (LIME)

Black-box Induction



The black-box model's complex decision function f (unknown to LIME) is represented by the blue/pink background. The bright bold red cross is the instance being explained. LIME samples instances, gets predictions using f, and weighs them by the proximity to the instance being explained (represented here by size). The dashed line is the learned explanation that is locally (but not globally) faithful. .

Example Explanation



(a) Original Image (b) Explaining *Electric guitar* (c) Explaining *Acoustic guitar*

- **LIME** is an algorithm that can explain the predictions of any classifier in a faithful way, by approximating it locally with an interpretable model.

- **SP-LIME is** a method that selects a set of representative instances with explanations as a way to characterize the entire model.

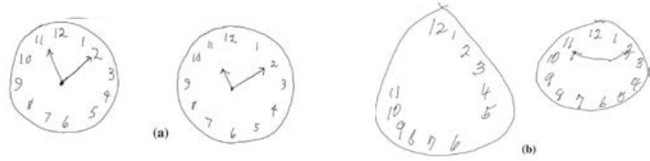
Ribeiro, M.T., Singh, S., and Guestrin, C. (2016). "Why Should I Trust You?" Explaining the Predictions of Any Classifier. *CHI 2016 Workshop on Human Centered Machine Learning. (arXiv:1602.04938v1 [cs.LG] 16 Feb 2016)*

Model Induction

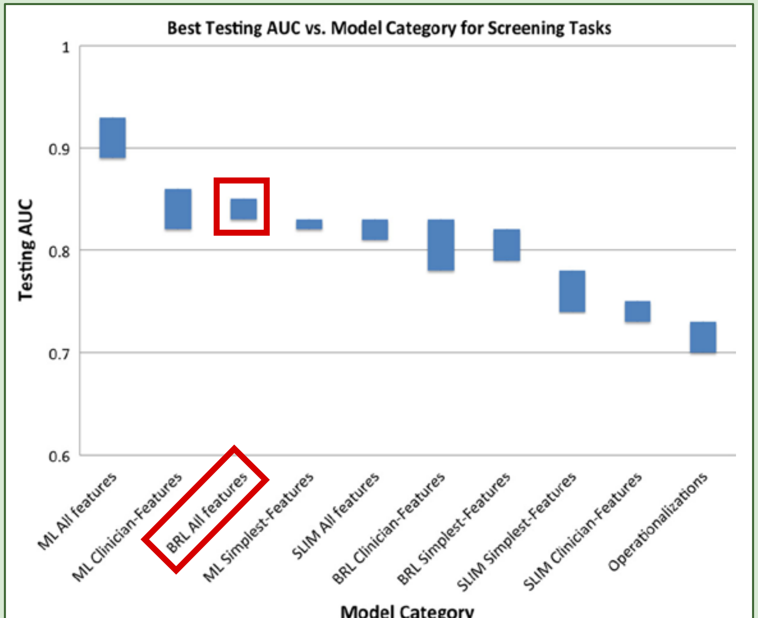
Bayesian Rule Lists (BRL)

- **if** hemiplegia and age > 60
  - **then** stroke risk 58.9% (53.8%–63.8%)
- **else if** cerebrovascular disorder
  - **then** stroke risk 47.8% (44.8%–50.7%)
- **else if** transient ischaemic attack
  - **then** stroke risk 23.8% (19.5%–28.4%)
- **else if** occlusion and stenosis of carotid artery without infarction
  - **then** stroke risk 15.8% (12.2%–19.6%)
- **else if** altered state of consciousness and age > 60
  - **then** stroke risk 16.0% (12.2%–20.2%)
- **else if** age ≤ 70
  - **then** stroke risk 4.6% (3.9%–5.4%)
- **else** stroke risk 8.7% (7.9%–9.6%)

Clock Drawing Test



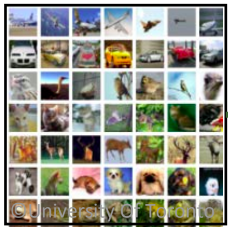
Normal Function   Cognitive Impairment



- BRLs are decision lists--a series of if-then statements
- BRLs discretize a high-dimensional, multivariate feature space into a series of simple, readily interpretable decision statements.
- Experiments show that BRLs have predictive accuracy on par with the current top ML algorithms (approx. 85-90% as effective) but with models that are much more interpretable

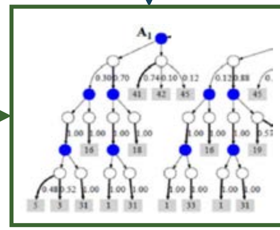
Letham, B., Rudin. C., McCormick, T., and Madigan, D. (2015). Interpretable classifiers using rules and Bayesian analysis: Building a better stroke prediction model. *Annals of Applied Statistics 2015*, Vol. 9, No. 3, 1350-137

Explainable AI – Why Do You Think It Will Be Successful?



Training Data

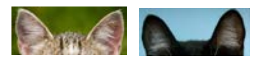
New Learning Process



Explainable Model

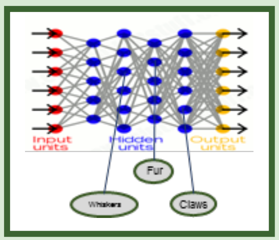
This is a cat:

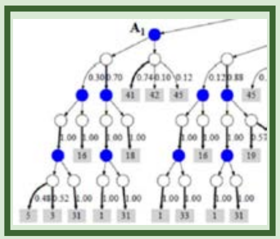
- It has fur, whiskers, and claws.
- It has this feature:

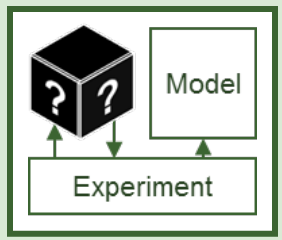


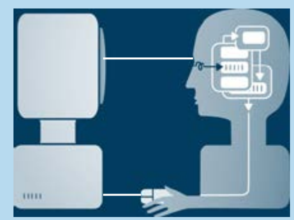
Explanation Interface

- I understand why
- I understand why not
- I know when you'll succeed
- I know when you'll fail
- I know when to trust you
- I know why you erred









Deep Explanation	Interpretable Models	Model Induction	HCI	Psychology
Learning Semantic Associations H. Sawhney (SRI Sarnoff)	**Stochastic And-Or-Graphs (AOG)** Song-Chun Zhu (UCLA)	**Local Interpretable Model-agnostic Explanations (LIME)** C. Guestrin (UW)	**Prototype Explanation Interface** T. Kulesza (OSU/MSR)	**Principles of Explanatory Machine Learning** M. Burnett (OSU)
Learning to Generate Explanations T. Darrell, P. Abeel (UCB)	**Bayesian Program Learning** J. Tenenbaum (MIT)	**Bayesian Rule Lists** C. Rudin (MIT)	**UX Design, Language Dialog, Visualization** ENGINEERING PRACTICE	**Psychological Theories of Explanation** T. Lombrozo (UCB)

Explanation Interface – A Simple Example

Principles

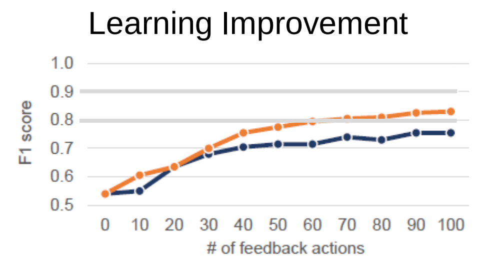
Explainability
- Be Iterative
- Be Sound
- Be Complete
- Don't Overwhelm

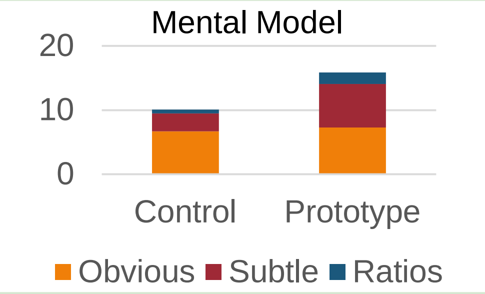
Correctability
- Be Actionable
- Always Honor User Feedback
- Incremental Changes Matter

Prototype

(A) List of folders; (B) List of messages in the folder; (C) The selected message; (D) Explanation of the message's predicted folder; (E) Overview of messages; (F) Complete list of words the system used to make predictions

Results

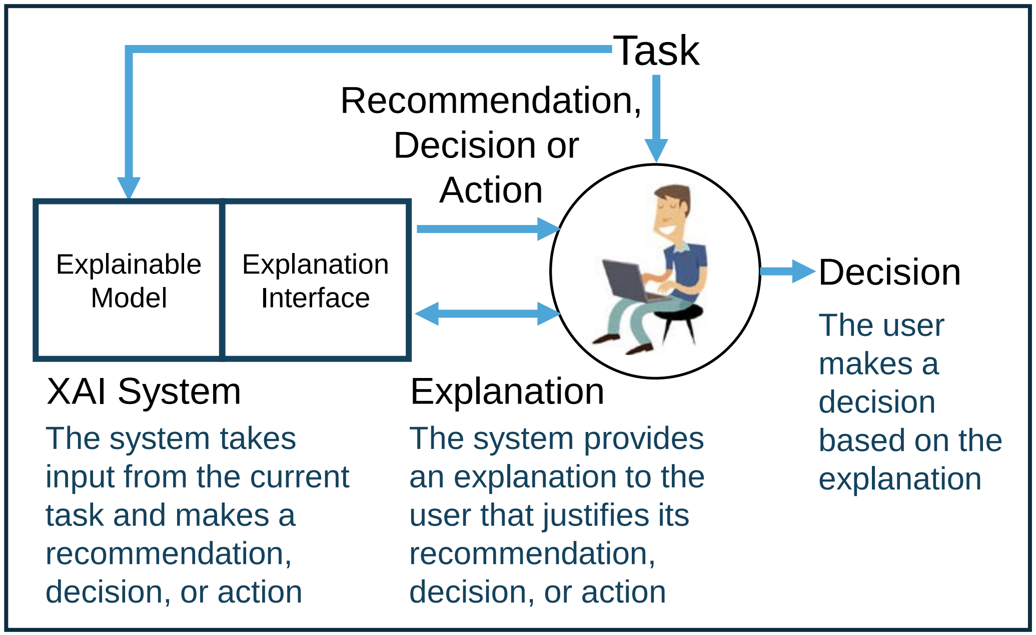




Kulesza, T., Burnett, M., Wong, W.-K., & Stumpf, S. (2015). Principles of Explanatory Debugging to Personalize Interactive Machine Learning. *IUI 2015, Proceedings of the 20th International Conference on Intelligent User Interfaces* (pp. 126-137).

Explainable AI – Measuring Evaluation Effectiveness

Explanation Framework



Measure of Explanation Effectiveness

User Satisfaction

- Clarity of the explanation (user rating)
- Utility of the explanation (user rating)

Mental Model

- Understanding individual decisions
- Understanding the overall model
- Strength/weakness assessment
- 'What will it do' prediction
- 'How do I intervene' prediction

Task Performance

- Does the explanation improve the user's decision, task performance?
- Artificial decision tasks introduced to diagnose the user's understanding

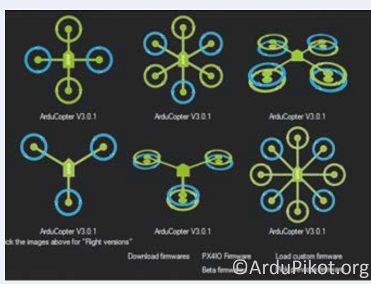
Trust Assessment

- Appropriate future use and trust

Correctablity

- Identifying errors
- Correcting errors
- Continuous training

Explainable AI – Challenge Problem Areas

	Learn a model to perform the task	Explain decisions, actions to the user	Use the explanation to perform a task	
Data Analytics Classification Learning Task	 Multimedia Data	Explainable Model → Explanation Interface Recommend Explanation		An analyst is looking for items of interest in massive multimedia data sets
	Classifies items of interest in large data set	Explains why/why not for recommended items	Analyst decides which items to report, pursue	
Autonomy Reinforcement Learning Task	 ArduPilot & SITL Simulation	Explainable Model → Explanation Interface Actions Explanation		An operator is directing autonomous systems to accomplish a series of missions
	Learns decision policies for simulated missions	Explains behavior in an after-action review	Operator decides which future tasks to delegate	

www.darpa.mil

Leading the world to 5G

February 2016
Qualcomm Technologies, Inc.

Our 5G vision: a unifying connectivity fabric

5G

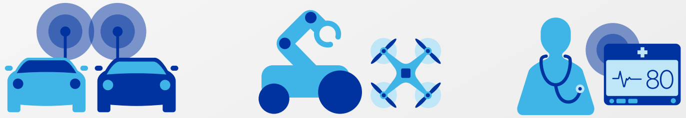
Enhanced mobile broadband

- Multi-Gbps data rates
- Extreme capacity
- Uniformity
- Deep awareness

Mobile devices Networking

Mission-critical services

- Ultra-low latency
- High reliability
- High availability
- Strong security



Automotive Robotics Health

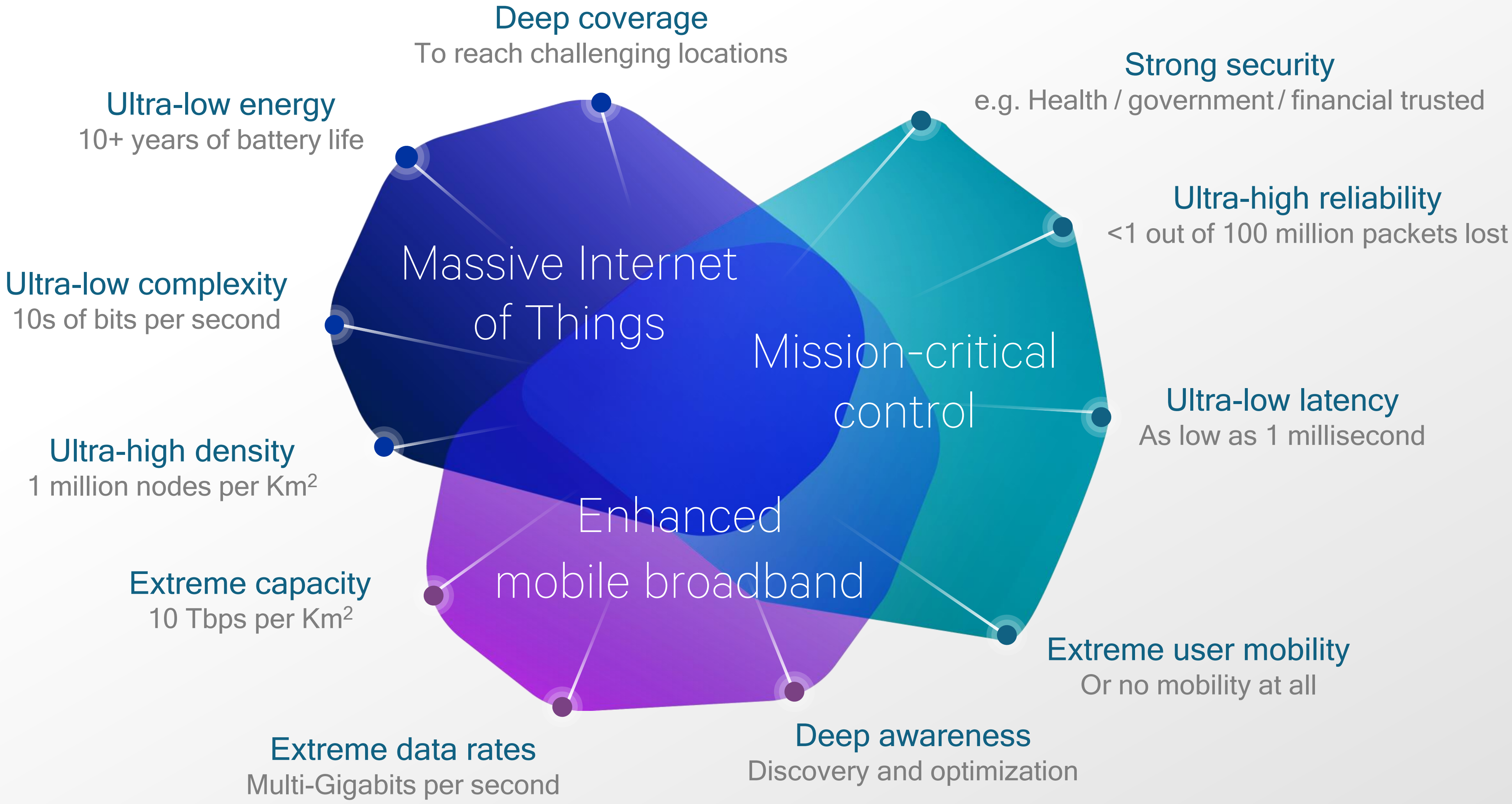
Massive Internet of Things

- Low cost
- Ultra-low energy
- Deep coverage
- High density

Wearables Smart cities Smart homes

Unified design for all spectrum types and bands from below 1GHz to mmWave

Scalable to an extreme variation of requirements



Based on target requirements for the envisioned 5G use cases

Enhancing mobile broadband

Ushering in the next era of immersive experiences and hyper-connectivity


3D/UHD video telepresence


Tactile Internet


UHD video streaming


Demanding conditions, e.g. venues


Broadband ‘fiber’ to the home


Virtual reality

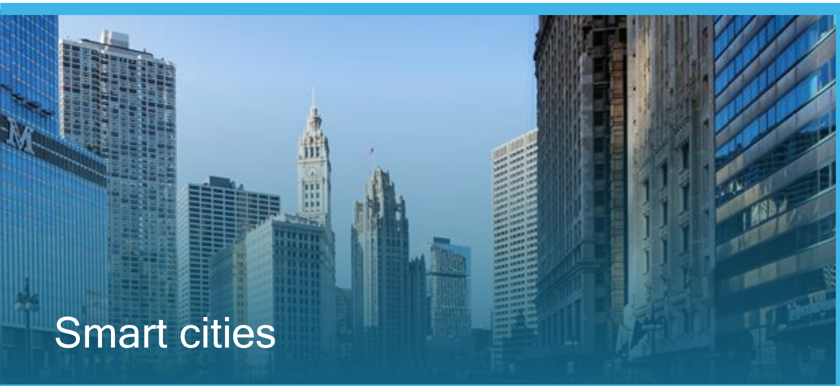
Extreme throughput
multi-gigabits per second

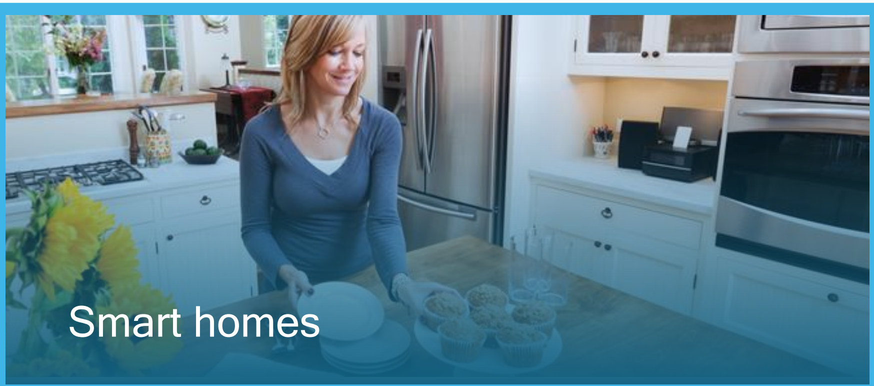
Ultra-low latency
down to 1ms e2e latency

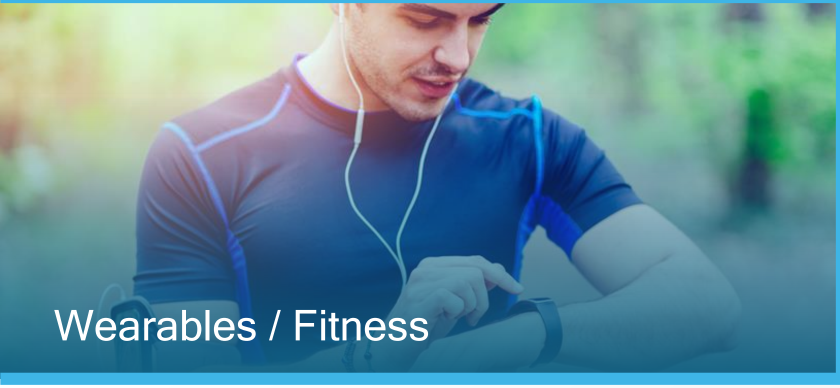
Uniform experience
with much more capacity

Connecting the massive Internet of Things

Optimizing to connect anything, anywhere with efficient, low cost communications







Power efficient
Multi-year battery life

Low complexity
Low device and network cost

Long range
Deep coverage

Enabling new mission-critical control services

With ultra-reliable, ultra-low latency communication links

High reliability
Extremely low loss rate

Ultra-low latency
Down to 1ms e2e latency

High availability
Multiple links for failure tolerance & mobility

A unified 5G design for all spectrum types/bands

Addressing a wide range of use cases and deployment scenarios

Licensed Spectrum
Cleared spectrum
EXCLUSIVE USE

Shared Licensed Spectrum
Complementary licensing
SHARED EXCLUSIVE USE

Unlicensed Spectrum
Multiple technologies
SHARED USE

Below 1 GHz: longer range for massive Internet of Things

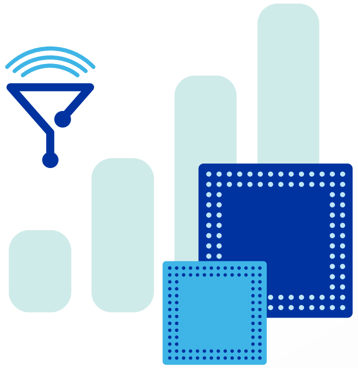
1 GHz to 6 GHz: wider bandwidths for enhanced mobile broadband and mission critical

Above 6 GHz, e.g. mmWave: extreme bandwidths, shorter range for extreme mobile broadband

From wide area macro to local hotspot deployments
Also support diverse network topologies (e.g. D2D, mesh)

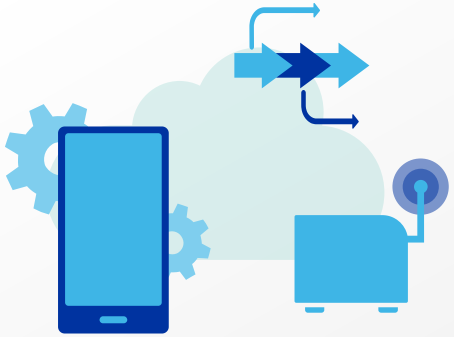
Qualcomm, leading the world to 5G

Investing in 5G for many years—building upon our leadership foundation



Wireless/OFDM technology and chipset leadership

Pioneering 5G technologies to meet extreme requirements



End-to-end system approach with advanced prototypes

Driving 5G from standardization to commercialization

Leading global network experience and scale

Providing the experience and scale that 5G demands

Pioneering 5G technologies today with LTE

We are driving 4G and 5G in parallel to their fullest potential

Advanced MIMO

Unlicensed spectrum

256QAM

Enhanced CA

FeICIC

Internet of Things

Carrier aggregation

FDD-TDD CA

Massive/FD-MIMO

CoMP

Device-to-device

Shared broadcast

SON+

Dual connectivity

V2X

Low latency

5G

Rel-15 and beyond

Further backwards-compatible 4G enhancements

Rel-10/11/12
LTE Advanced

Rel-13 and beyond
LTE Advanced Pro

2015

2020+

Note: Estimated commercial dates. Not all features commercialized at the same time

Driving new LTE technologies to commercialization

Pushing LTE towards 5G with our unique end-to-end system approach

End-to-end prototype platforms	Standards and research leadership	Industry-first trials with network operators	Industry-first chipsets*
First LTE Unlicensed live demo at MWC 2014	Pioneered LTE Unlicensed work in 3GPP	First LAA over-the-air trial in November 2015	First modem and small cell solution to support LAA

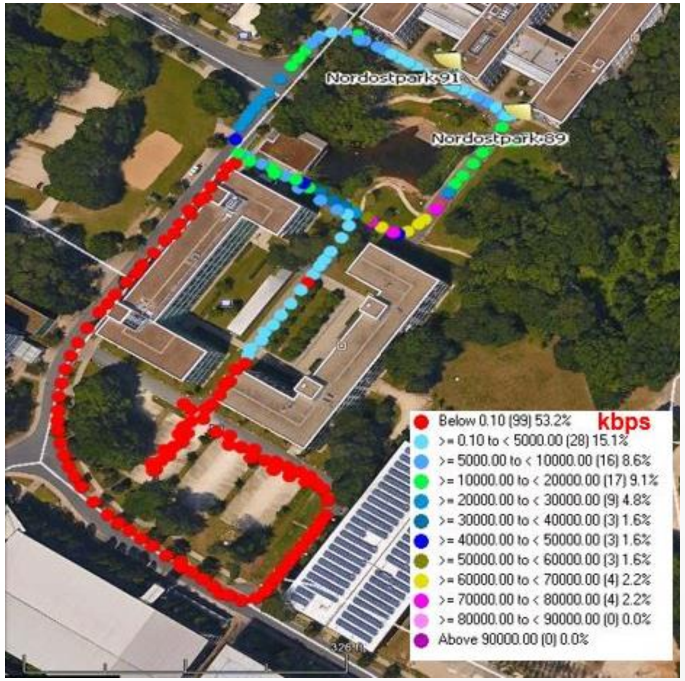
Example: Driving LTE Unlicensed to commercialization

* Chipsets are products of Qualcomm Technologies, Inc.; firsts with respect to public announcement of a commercial LTE modem chipset

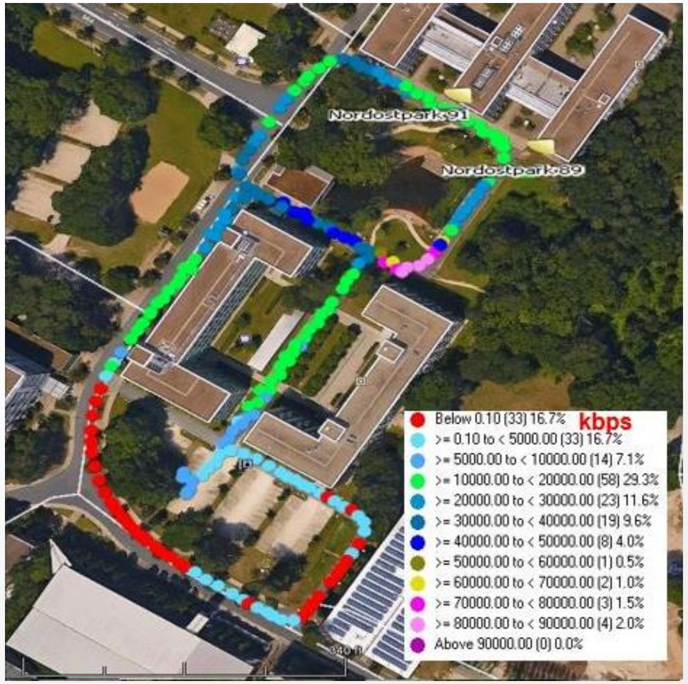
World’s first over-the-air LAA trial during November 2015

Joint effort by Qualcomm Technologies with Deutsche Telekom AG

LWA (Wi-Fi) test route*



LAA test route*



Coverage^ in unlicensed

Mbps	Wi-Fi	LAA
	x 2.5	
>10	24% of route	60% of route
	x 1.8	
>1	39% of route	71% of route
	x 1.7	
>0	47% of route	82% of route

Wide range of indoor and outdoor test cases

Demonstrated coverage and capacity benefits of LAA

Demonstrated fair co-existence with Wi-Fi

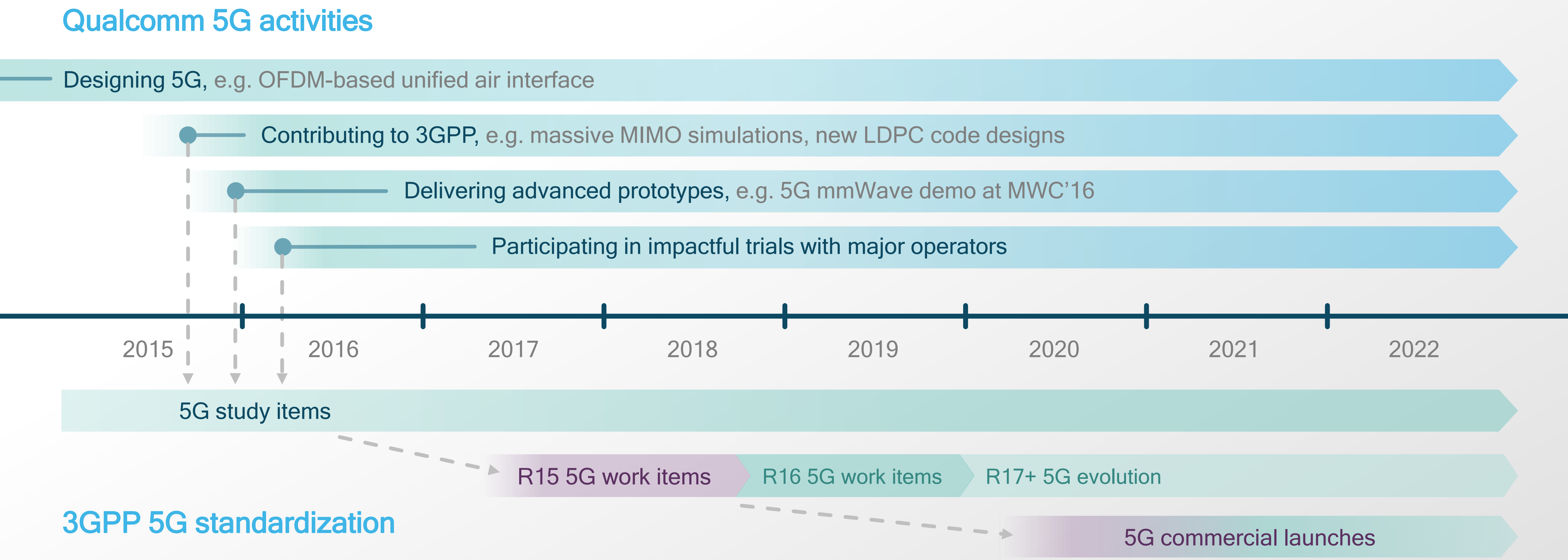
* Single small cell, LAA based on 3GPP release 13; LWA using 802.11ac; LTE on 10 MHz channel in 2600 MHz licensed spectrum with 4W transmit power; the following conditions are identical for LAA and Wi-Fi: 2x2 downlink MIMO, same 20 MHz channel in 5 GHz unlicensed spectrum with 1W transmit power, terminal transmit power 0.2W, mobility speed 6-8 mph; ^ Based on geo-binned measurements over test route

Multi-mode/multi-connectivity essential to 5G success

Simultaneous connectivity across 5G, 4G and Wi-Fi

Leading the world to 5G

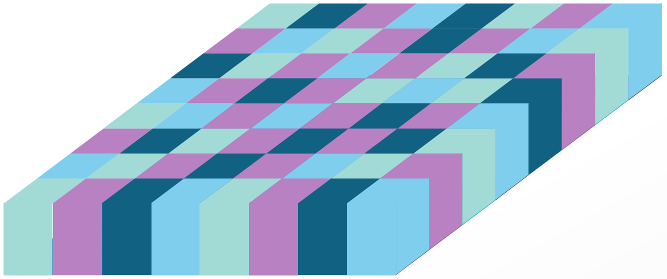
From standardization to commercialization

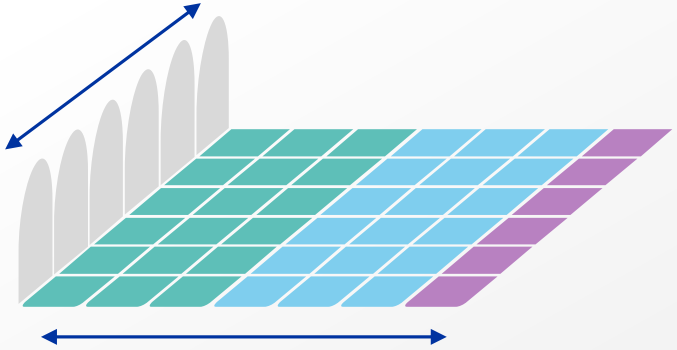


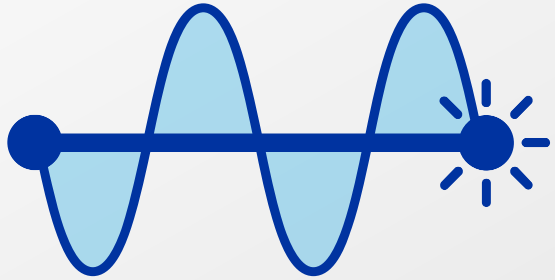
Note: Estimated commercial dates;

Designing a unified, more capable 5G air interface

Building on our strong OFDM/wireless foundation







Optimized OFDM-based waveforms

OFDM adapted to extremes

A common, flexible framework

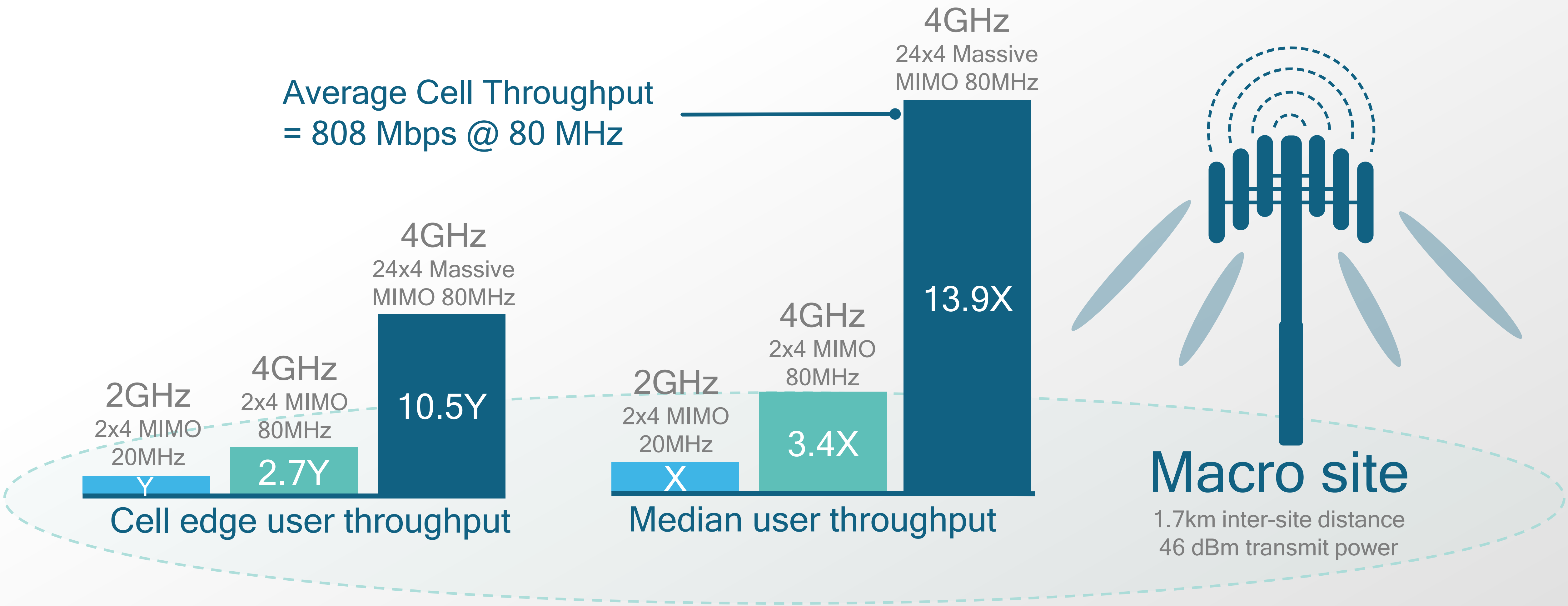
Designed for forward compatibility

Advanced wireless technologies

Such as massive MIMO, mmWave

Massive MIMO at 4 GHz allows reuse of existing sites

Leverage higher spectrum band using same sites and same transmit power



Source: Qualcomm Technologies, Inc. simulations; Macro-cell with 1.7km inter-site distance, 10 users per cell, 46 dBm Tx power at base station, 20MHz@2GHz and 80MHz@4GHz BW TDD, 2.4x Massive MIMO

Realizing the mmWave opportunity for mobile broadband

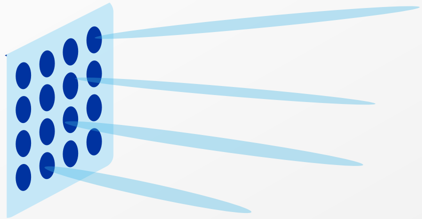
The extreme mobile broadband opportunity

- Large bandwidths, e.g. 100s of MHz
- Multi-Gpbs data rates
- Flexible deployments (integrated access/backhaul)
- High capacity with dense spatial reuse

The challenge–‘mobilizing’ mmWave

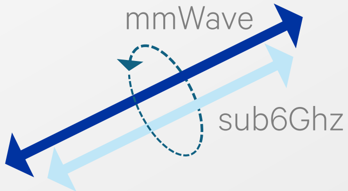
- Robustness due to high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G Solutions



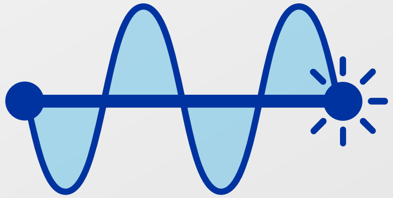
Intelligent directional beam forming & beam tracking

Increase coverage & provide continuous connectivity



Tight interworking with sub 6 GHz

Increase robustness and faster system acquisition



Optimized mmWave design for mobile

To meet cost, power & thermal constraints

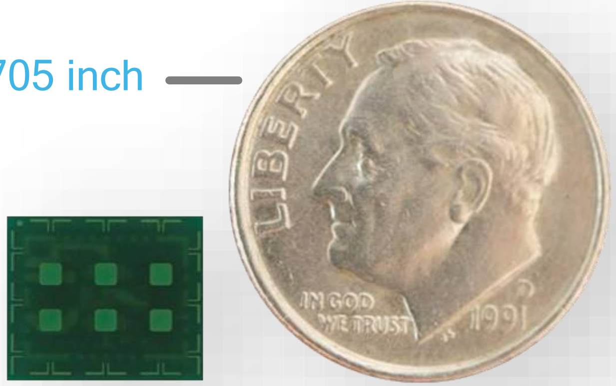
Making mmWave a reality for mobile

Qualcomm is driving 5G mmWave

60 GHz chipset commercial today for mobile devices

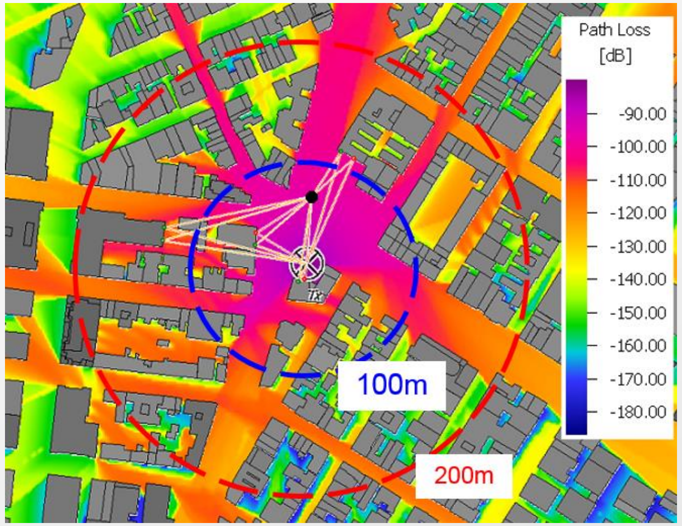
0.705 inch

0.28 inch



Qualcomm® VIVE™ 802.11ad technology with a 32-antenna array element

Developing robust 5G mmWave for extreme mobile broadband



Manhattan 3D map

Results from ray-tracing^

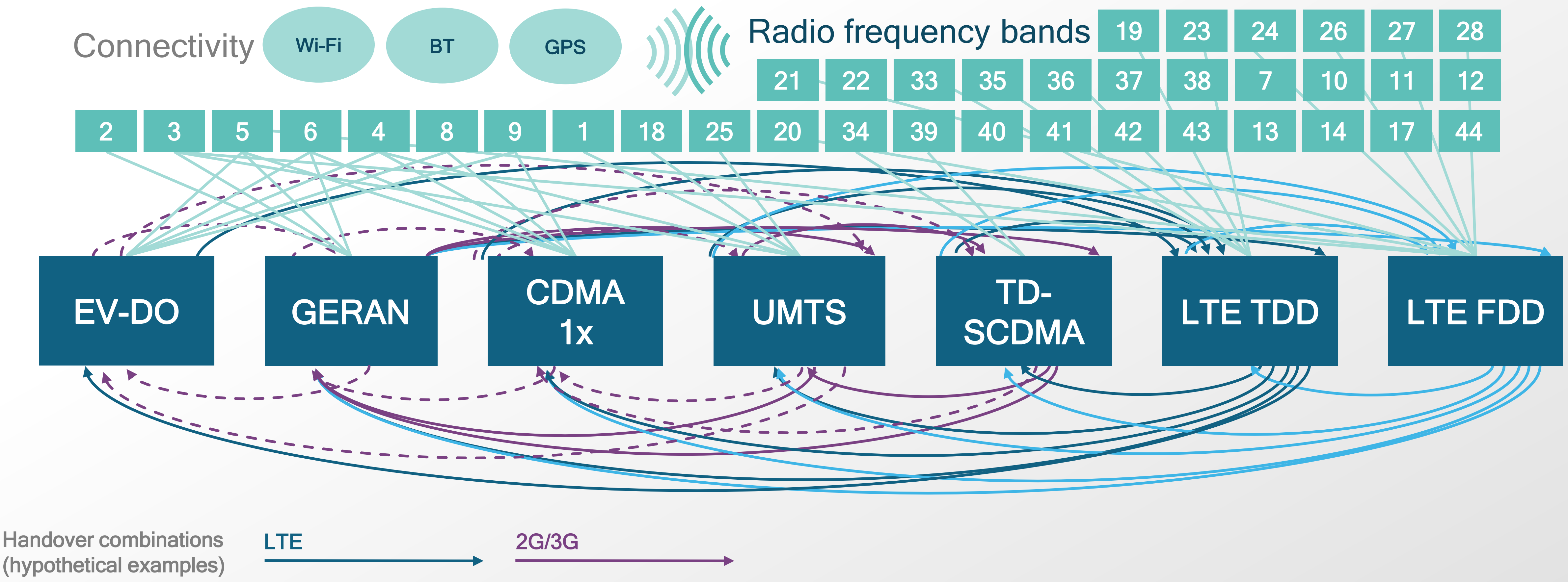
28 GHz outdoor example with ~150m dense urban LOS and NLOS coverage using directional beamforming^

Qualcomm VIVE is a product of Qualcomm Atheros, Inc.;

^ Based on Qualcomm Technologies Inc. simulations

Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving



Source: Qualcomm Technologies Inc.

2012 LTE Multimode

Today—LTE evolution

Tomorrow—5G and LTE evolution

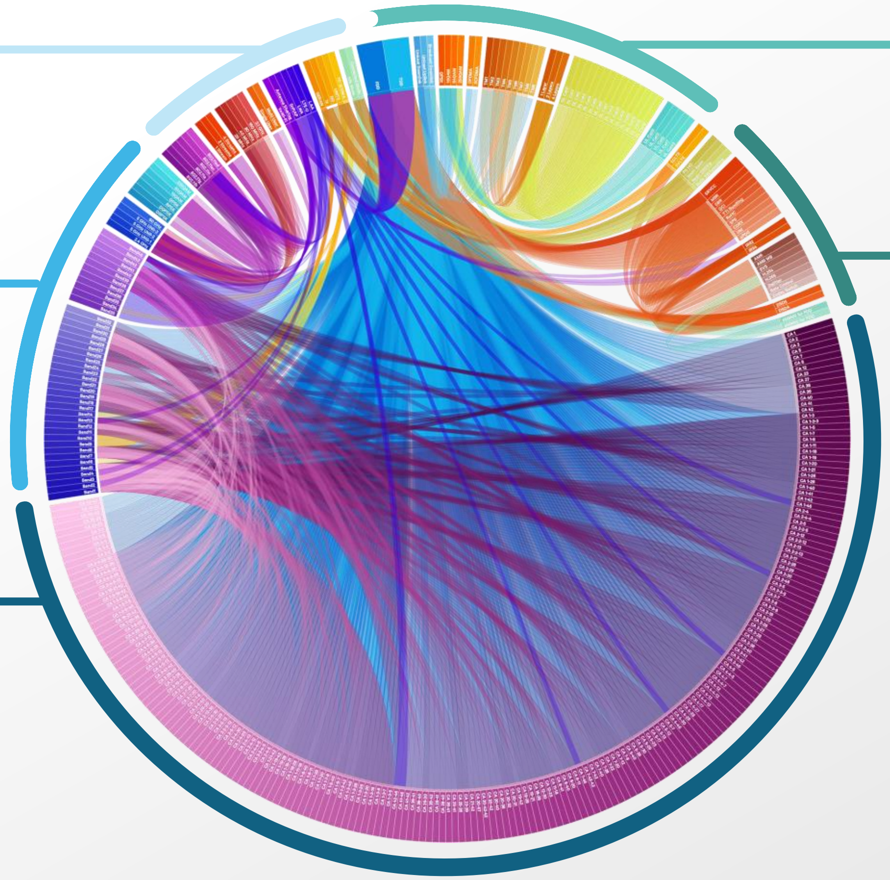
Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Wi-Fi, 3G, 2G technologies

50+ spectrum bands 450 MHz-5.8 GHz (licensed and unlicensed)

~200 Carrier Aggregation combinations



4G LTE OFDM-based waveforms, transmission modes, and UE categories

New LTE services, e.g. LTE Broadcast, VoLTE

2000+

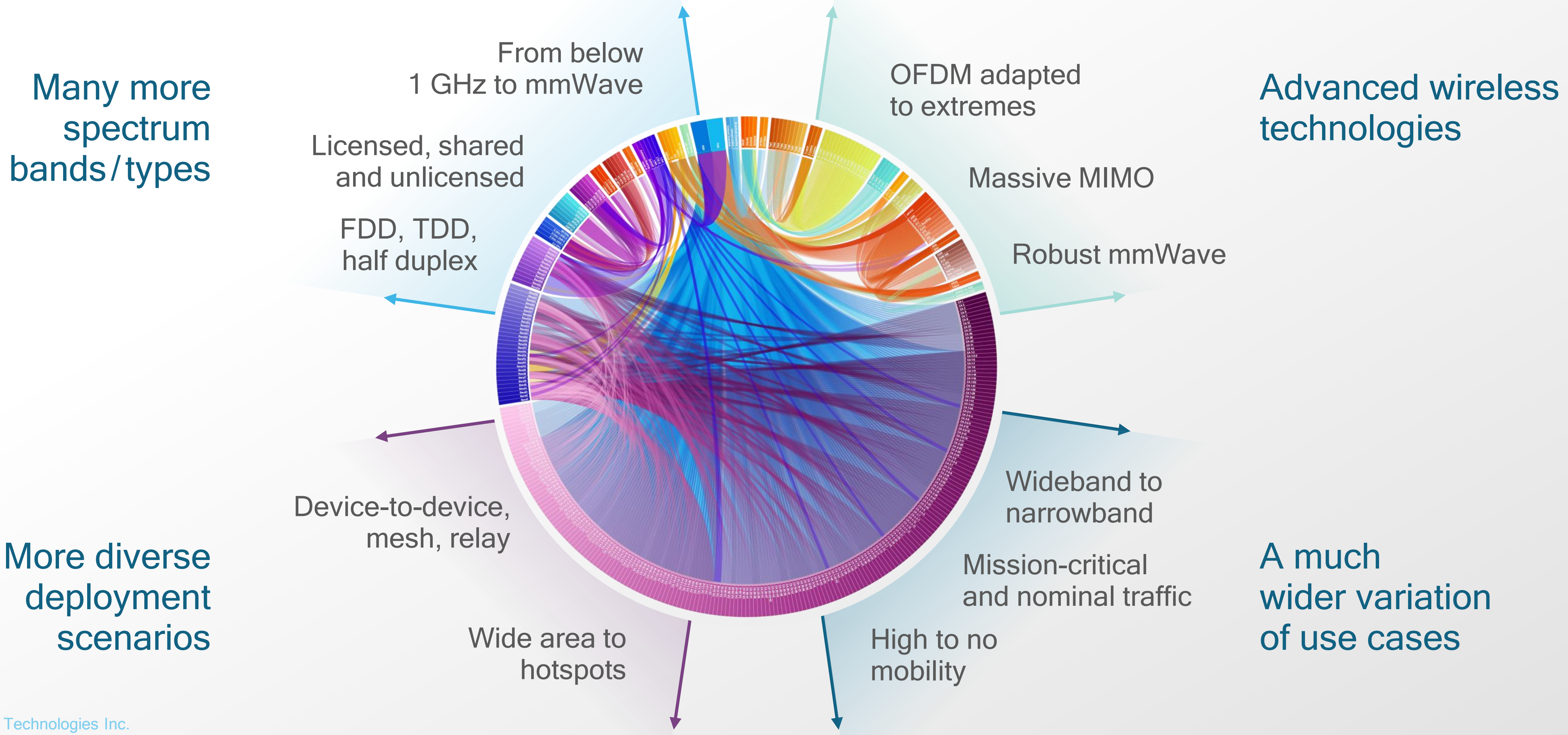
modem features to-date and counting

Source: Qualcomm Technologies Inc.

2012 LTE Multimode | Today–LTE evolution | Tomorrow–5G and LTE evolution

Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving



Source: Qualcomm Technologies Inc.

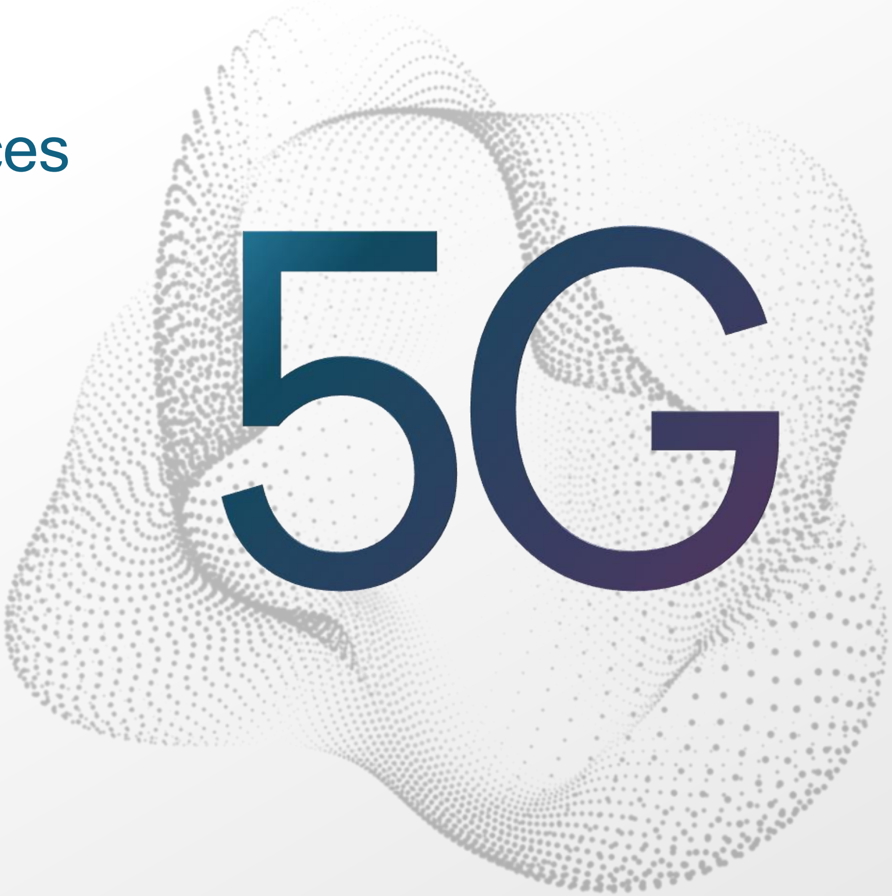
2012 LTE Multimode | Today–LTE evolution | Tomorrow—5G and LTE evolution

Leading the world to 5G

A unifying connectivity fabric for the next decade and beyond

Connecting new industries and devices

Empowering new user experiences



Enabling new services

Delivering new levels of efficiency

Questions? - Connect with Us

www.qualcomm.com/wireless

BLOG

www.qualcomm.com/news/onq

@Qualcomm_tech

http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp

http://www.slideshare.net/qualcommwirelessevolution

Thank you

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IoT and 5G: spectrum and networking

Elias Tragos

Research associate

Telecommunications and Networks Laboratory,

Institute of Computer Science,

Foundation for Research and Technology, Hellas.

IoT challenges

- Nodes
  - low processing capacity
  - low memory capacity
  - low storage capacity
  - power constrained
  - self configuration
  - diverse capabilities

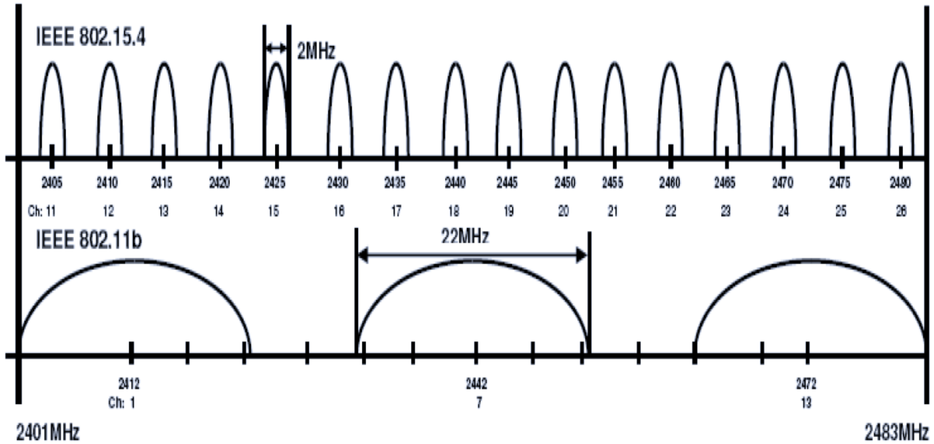
IoT challenges

- Network
  - Power consumption by network operations
  - Robustness/Redundancy
    - Node fault tolerance
    - Communication fault tolerance
  - Security/privacy
  - Scalability
  - Diverse traffic demands (!)
    - High throughput, high delay
    - Emergency (low throughput, low delay)
    - Bursty
  - Big data
  - Interference
  - deployment cost

IoT challenges

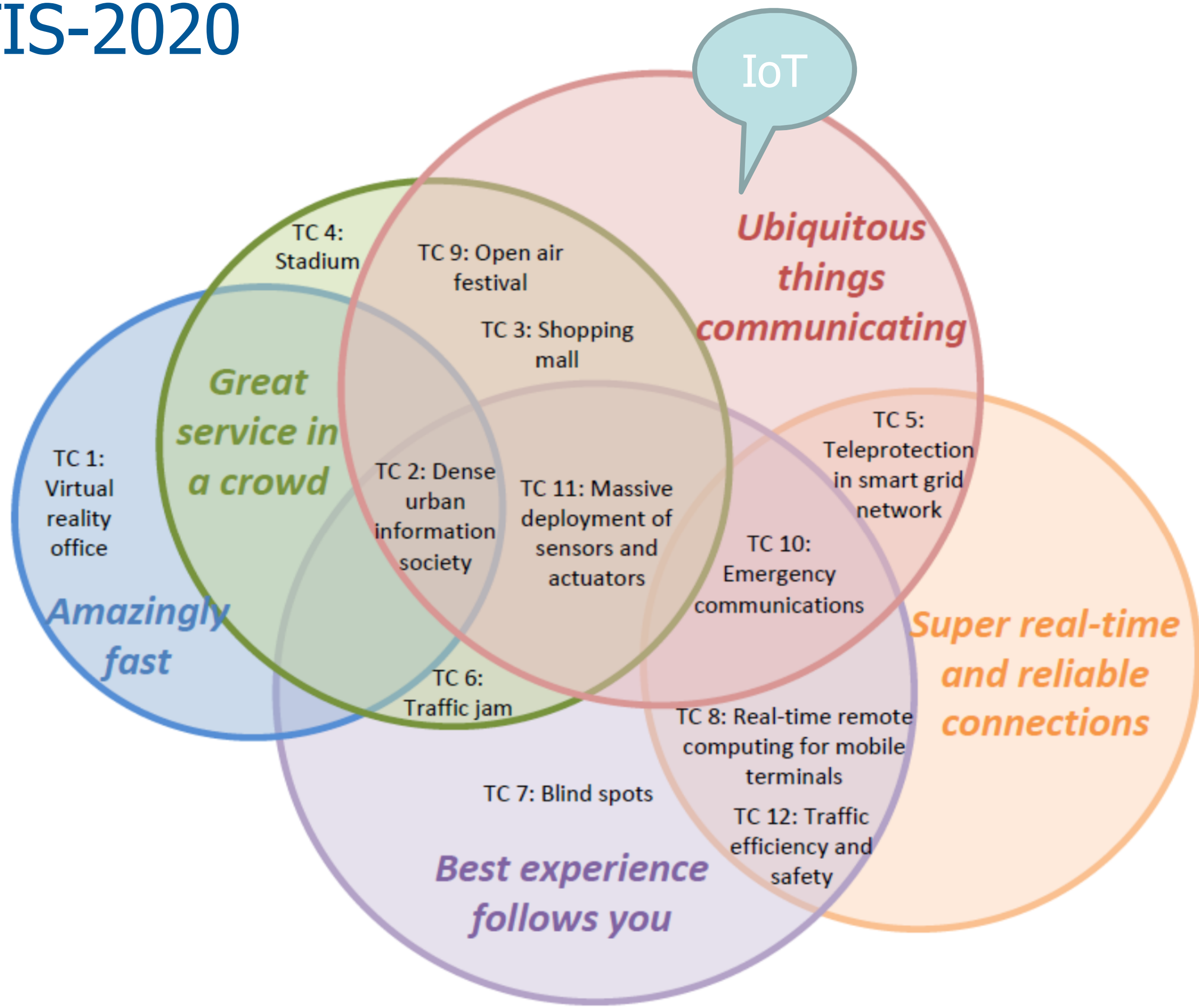
Spectrum issues

- Unlicensed bands are overcrowded
  - Wifi
  - Bluetooth
  - Wireless microphones
  - Microwave ovens
- Unlicensed bands cannot support large scale WSNs
  - communicating devices with little or no human intervention
  - M2M/IoT
  - devices respond to events
    - congestion
- Licensed bands cost



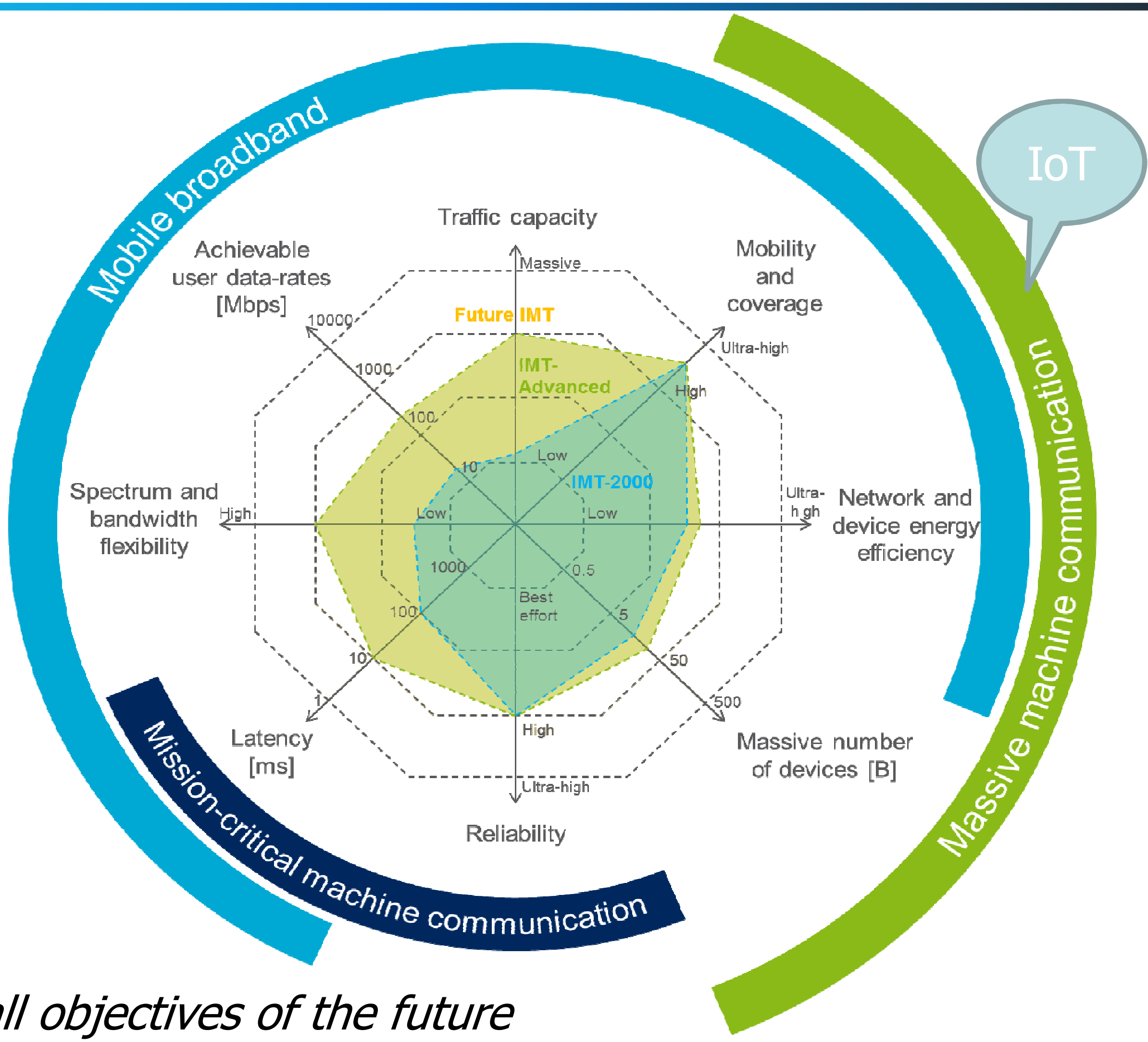
5G scenarios and IoT

- METIS-2020



5G scenarios and IoT

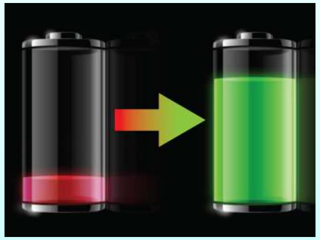
- *IMT Vision*



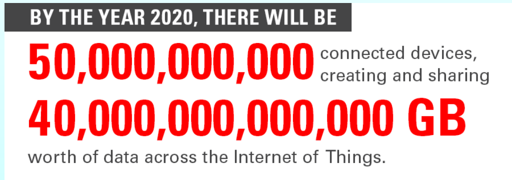
"Framework and overall objectives of the future development of IMT for 2020 and beyond" feb14

IoT requirements for 5G

Energy efficiency

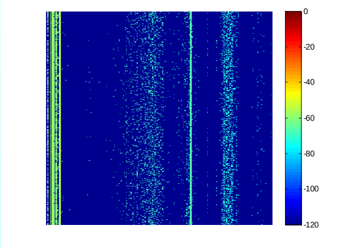


Scalability



Dense cells

Spectrum efficiency

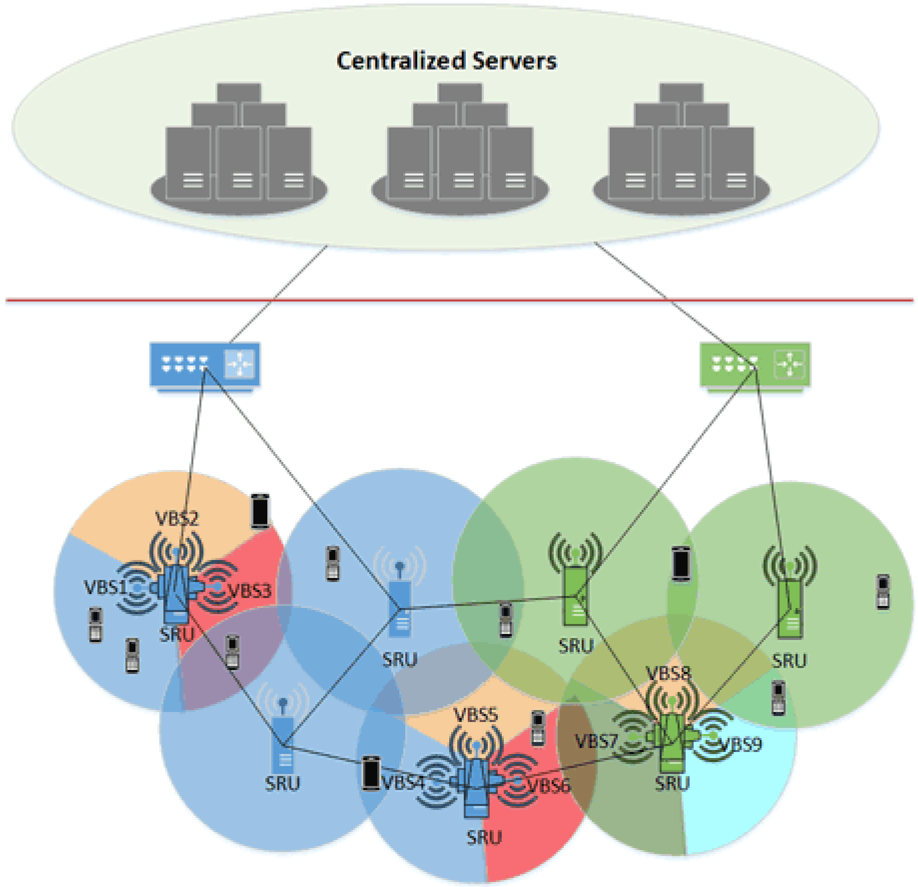


Cost efficiency

Constrained devices

5G solution for IoT

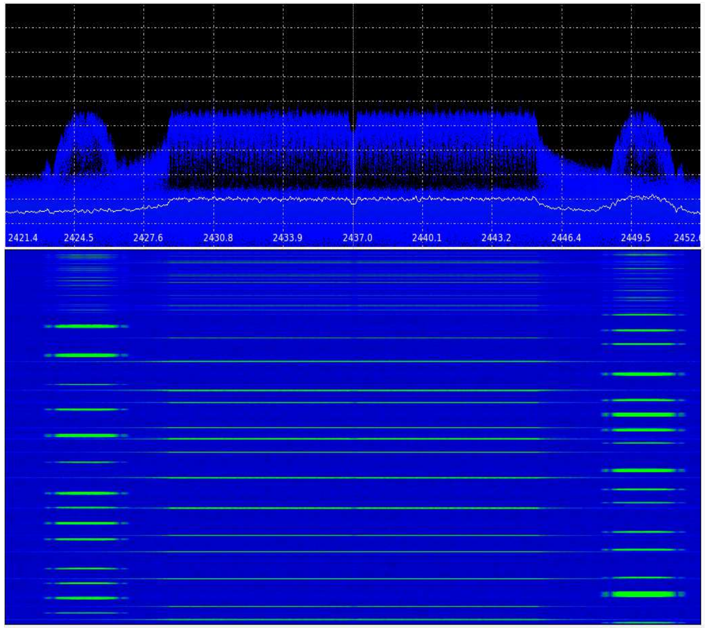
- SDR-based Cloud-RAN architecture
  - Energy efficient
  - Reprogrammable BSs
    - SDN
    - NFV
    - Multiple access
  - Hybrid network mgmt
  - Optimal resource allocation
    - Pool of BSs
    - Load balancing/offloading
    - Service prioritization
  - Cost efficient

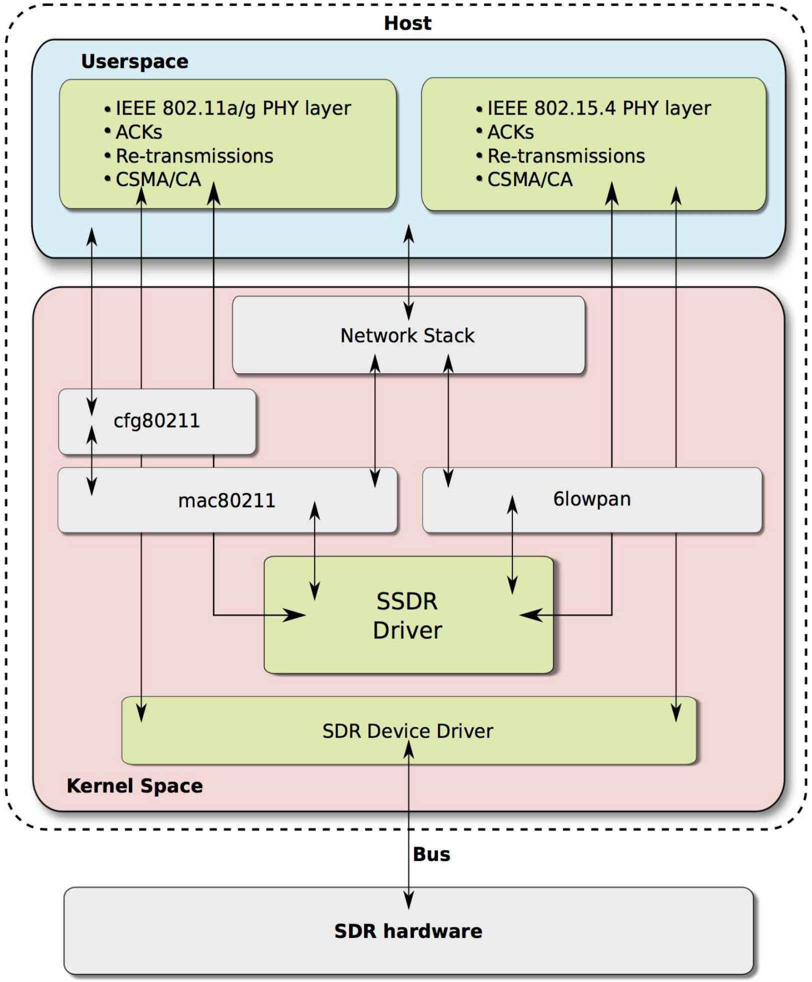


*ercim news 101

5G solution for IoT

- SDR-based Base Stations
  - 1 network interface card
  - Virtual interfaces
  - Multiple technologies
    - 802.11g
    - 802.15.4/6LowPAN





The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 609094.

www.ict-rerum.eu

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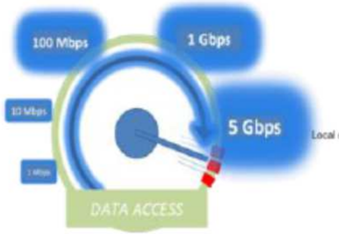
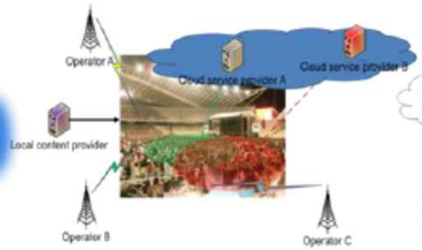
www.ict-rerum.eu

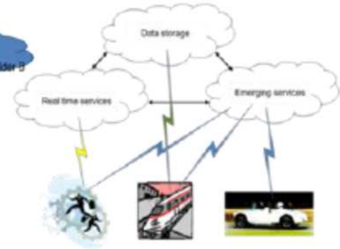
5G scenarios and IoT

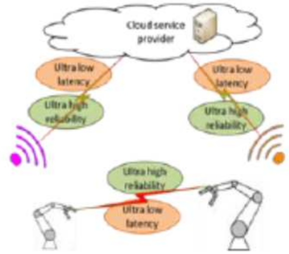
- METIS-2020

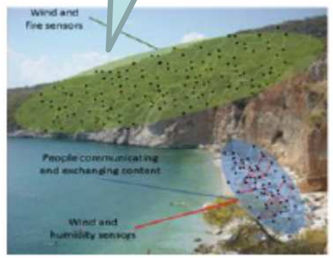
IoT



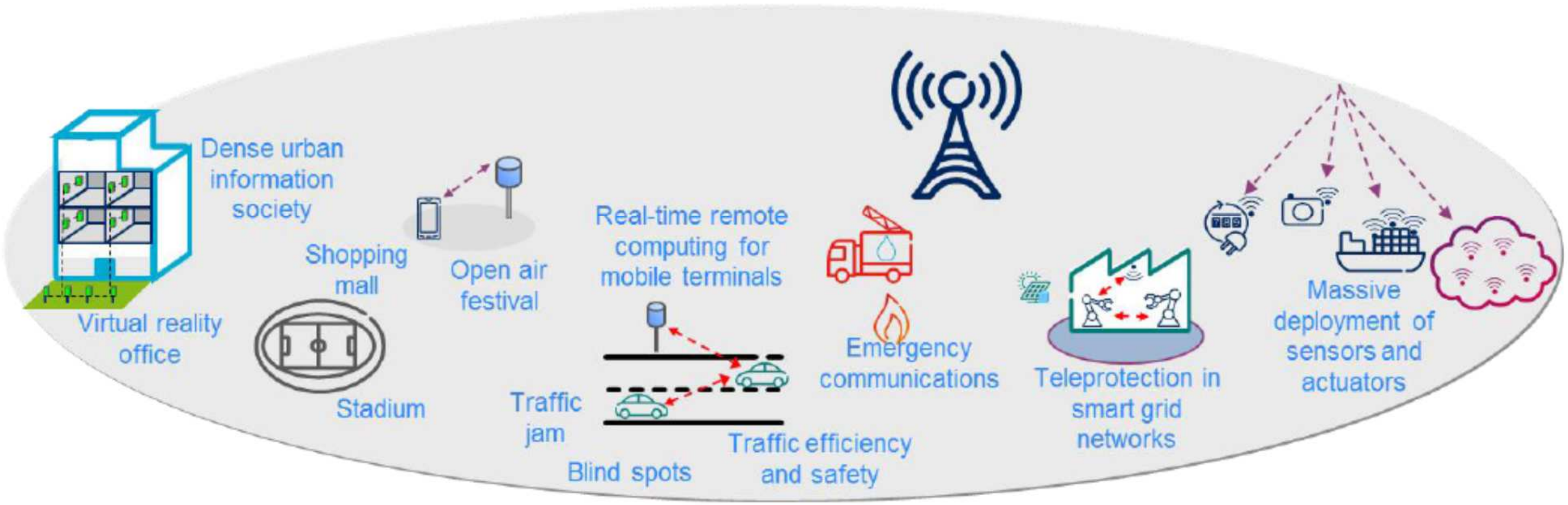








Amazingly fast | **Great service in a crowd** | **Best experience follows you** | **Super real-time and reliable connections** | **Ubiquitous things communicating**



NOKIA Bell Labs

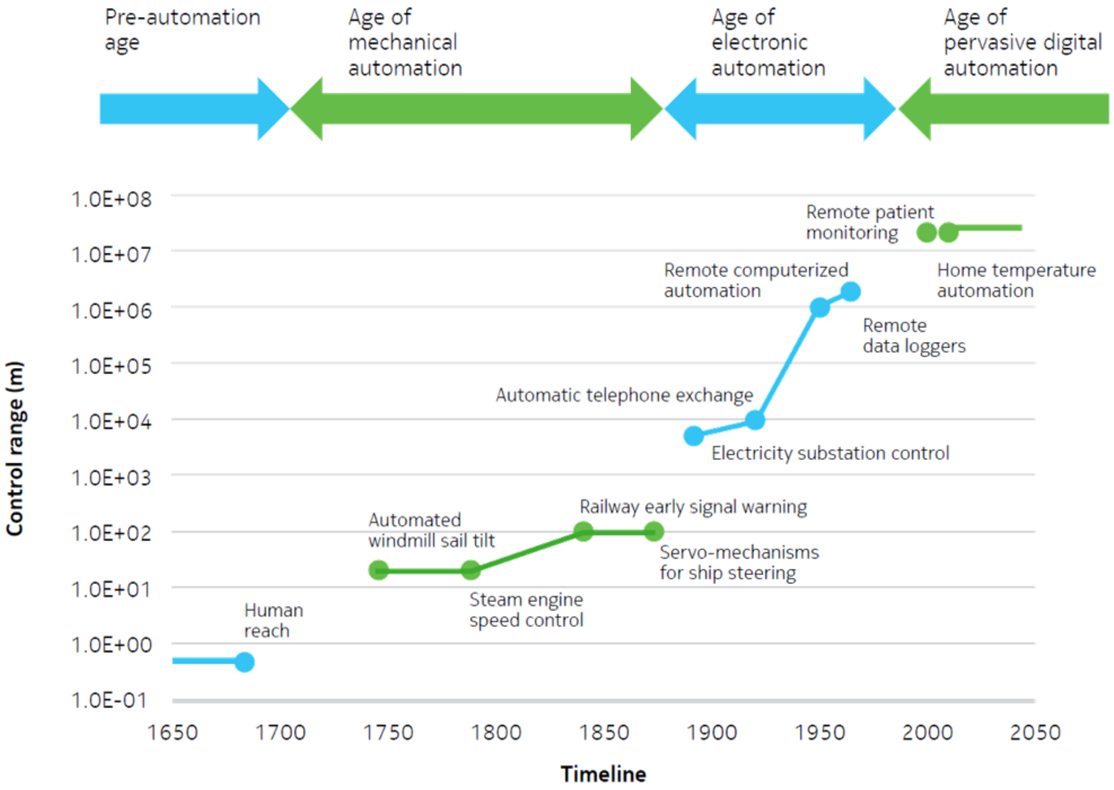
Future of IoT

The Transformation to Pervasive Digital Automation

Christele Bouchat

This presentation does not include mission critical communication

The Four Ages of Automation

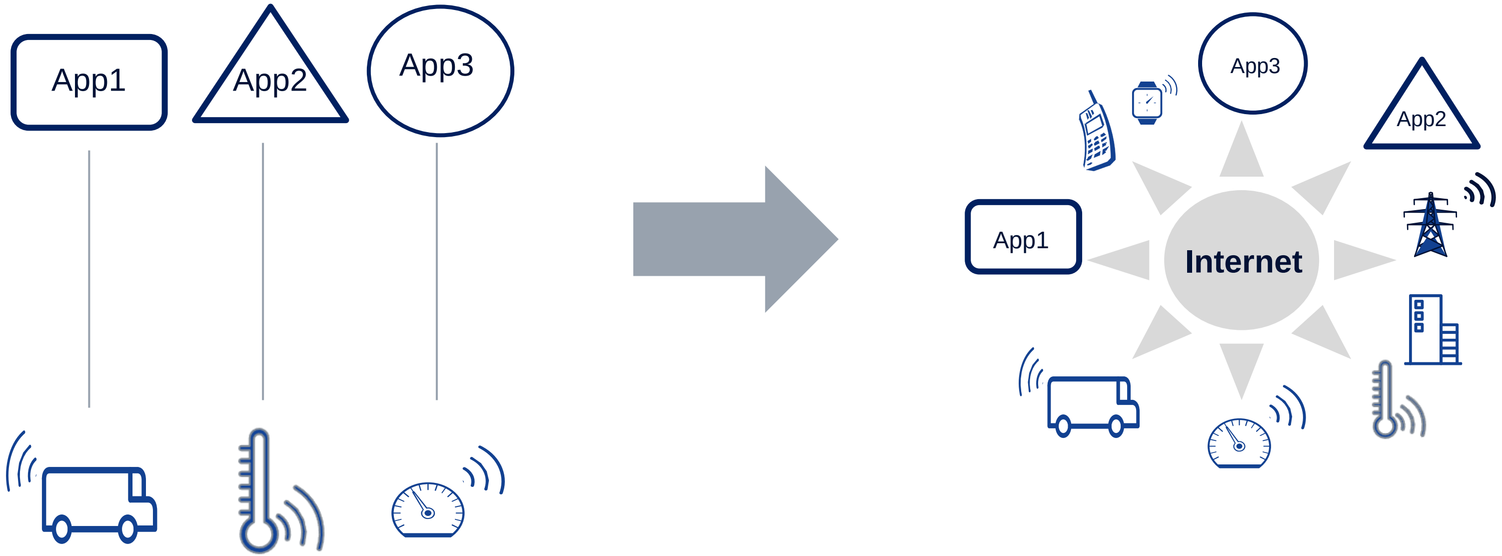


We are at the threshold of a new era in automation that dwarfs the previous eras in scale, speed, reach, diversity with major impact to how we live

NOKIA Bell Labs

The Transformation from Point Solutions to IoT

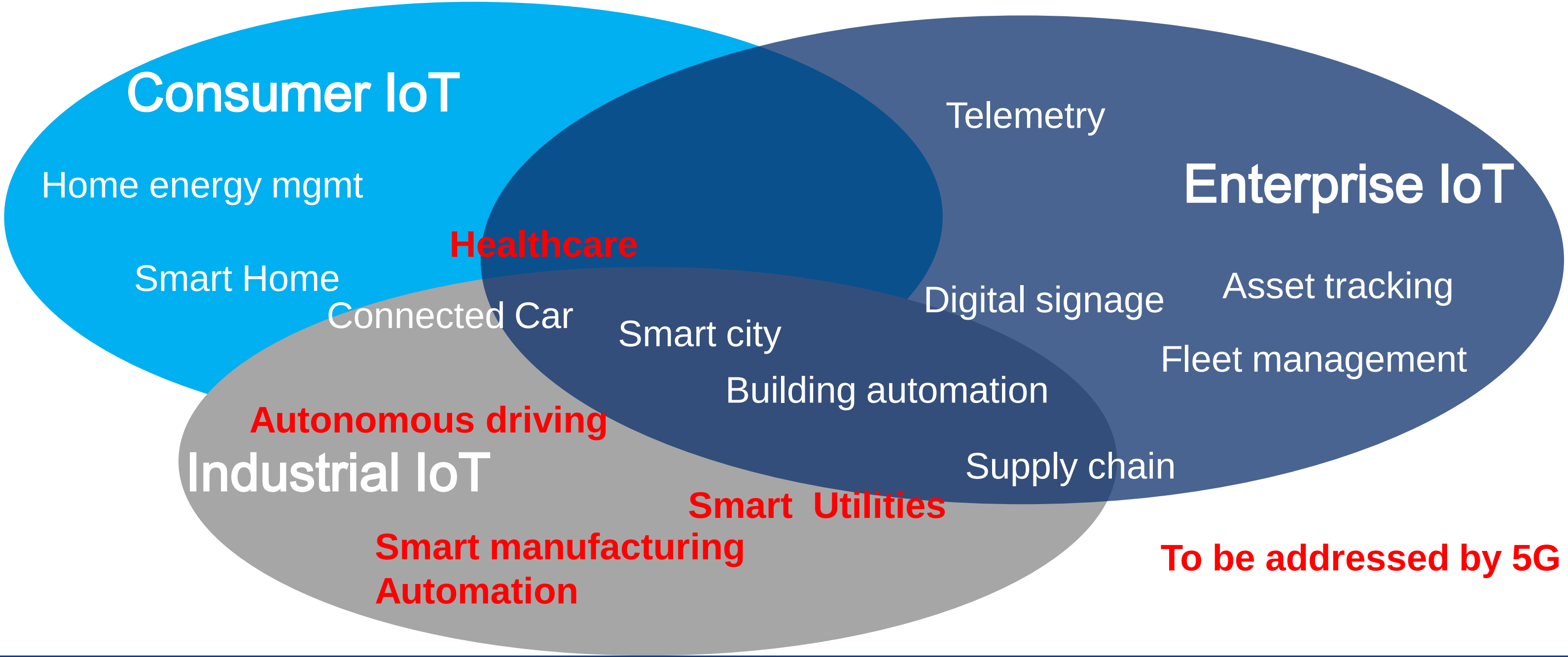
From the Intranet of Things to the Internet of Things



A shift from point to point monitoring and control solutions to a connection to the Internet is driving the large scale digitization of things

Segmentation in to Verticals

Consumer, Enterprise and Industrial IoT

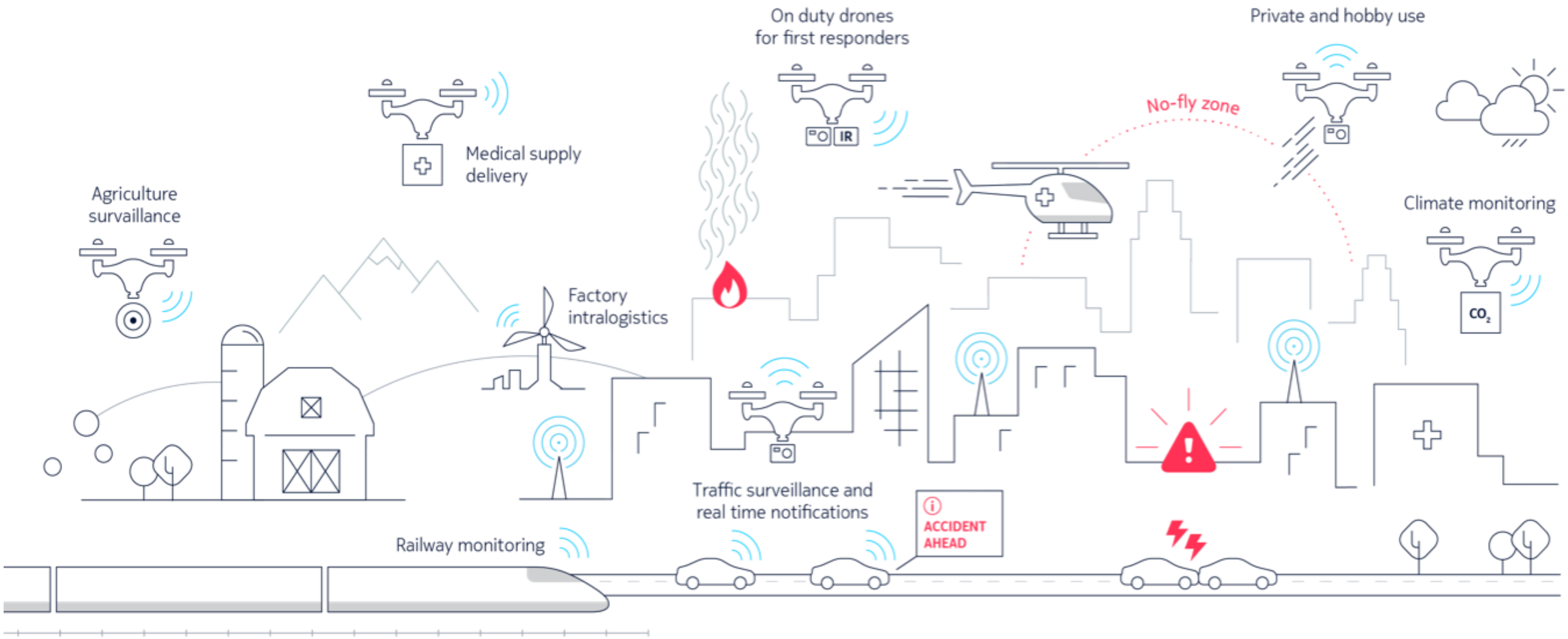


Significant variation in market penetration and growth across verticals with Industrial IoT in infancy & Consumer and Enterprise IoT accelerating

Unmanned Aerial Vehicles for Smart Solutions

With LTE: not very efficient because of interferences

5G to improve the quality of the link



NOKIA Bell Labs

Latency and Reliability Requirements

Reliability: high / low

eHealth
(body sensors)
- Relaxed Latency needs
- High reliability requirements
- Specialty: Long battery lifetime required

Automotive
- E2E latency < 5-10 ms [1)]
- Reliability up to BLER 10^{-6}
- Specialty: Mobility
- Positioning accuracy 0.5m

Industry Automation
- E2E latency partially < 0.5 ms
- Reliability up to BLER 10^{-9} [2)]
- Specialty: Often isolated areas

Smart Grid
- Moderate to high latency and reliability requirements
- Specialty: Large distances to be covered

Augmented Reality
- E2E latency < 10 ms to avoid cyber sickness
- Reliability requirements less tough (but need to detect failures reliably)
- Specialty: High data rates

Remote robotics / surgery
- E2E latency < 1 ms due to need for haptic feedback
- Reliability up to BLER 10^{-9}

Latency: high / low

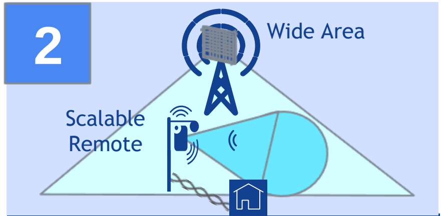
1) METIS D1.1
2) A. Frotzscher et al., Requirements and current solutions of wireless communication in industrial automation, ICC 2014

Technologies Enabling the Pervasive Digital Automation

Smart Devices

Lost cost, energy efficient/autonomous, secure, miniaturized devices for machine connectivity

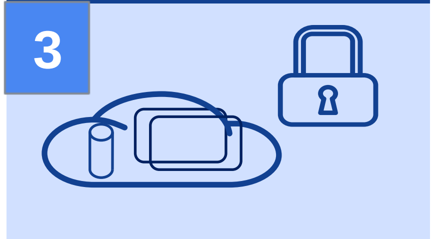
Massive Scale Connectivity



Wide area , short Range, low latency, ultra reliable, and Device to Device suitable for a broad range of applications

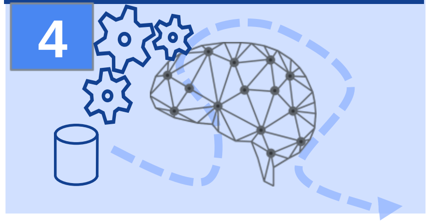
Secure IoT Platforms

Cloud based application enablement tools and connectivity management capabilities



Intelligent IoT Analytics

Real-time predictive analytics to drive autonomous systems



Low cost & power for massive machine type communication
3GPP LTE-M and NB-IoT

> 10 Years Battery life

Longer sleeping cycles

Less signaling for wakeup

Power save mode

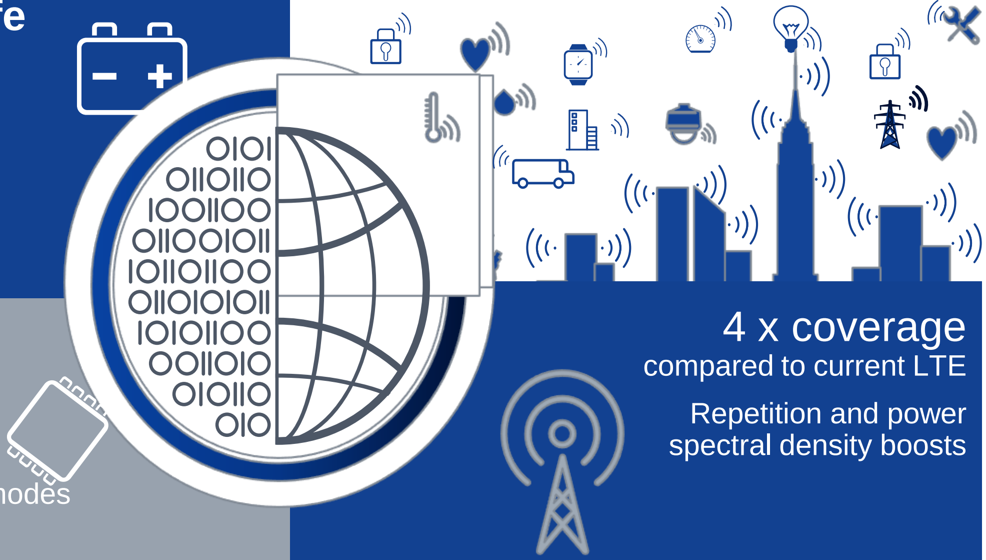
Low Cost Device

Narrowband transmission

Reduced transmit power

Limited downlink transmission modes

UE processing relaxations



4 x coverage
compared to current LTE

Repetition and power spectral density boosts

+15~20 dB coverage

Standardized in 2016

In 3GPP LTE

Need to be deployed

And learned from it

IoT to be included

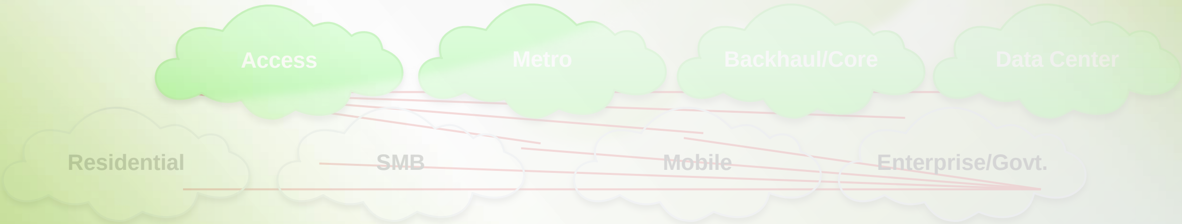
In latter phase of 5G

Expanding Cellular Connectivity to new IoT Application categories

broadband forum

Open Broadband

Click here for more info



Open Broadband

Open Broadband is collaborative space for the integration and testing of new open source, standards-based and vendor provided implementations

Collaboration between Open Broadband and other industry projects

- OB-I is the infrastructure platform that will provide physical lab resources to facilitate integration, testing, etc.
  - With other organizations such as ETSI NFV ISG, ONF, IETF, etc.
  - With open source projects (OPNFV, Open-O, OCP, ONOS, OpenCORD, Open Daylight, OpenStack, etc.) will provide implementations into the Open Broadband
  - With BBF projects such as CloudCO, BBF service modeling, the virtualized broadband network, 5G services, IoT,…
- Enables testing of integration for commercial deployments and vendor provided solutions

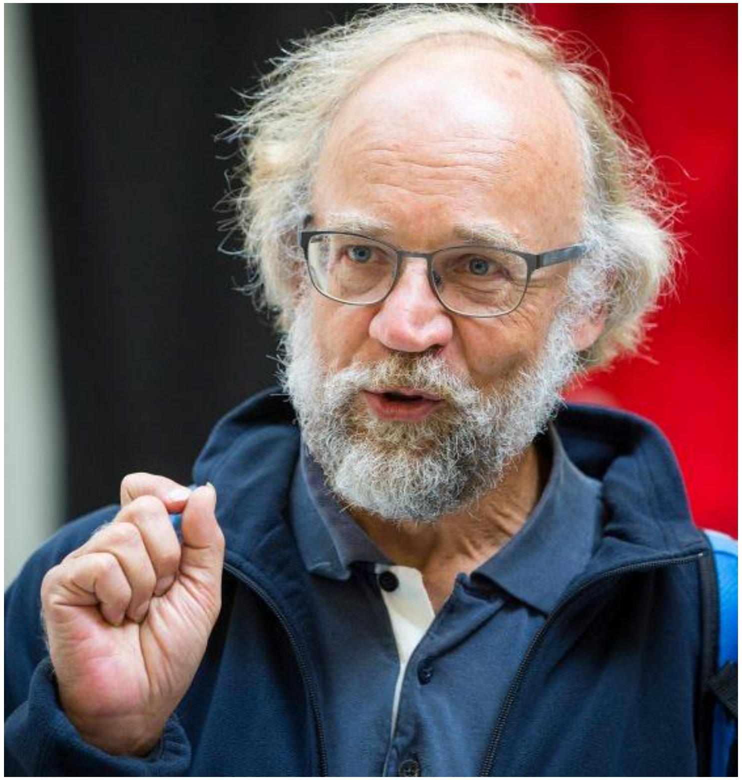
Industrial Internet, an IoT case for 5G

Martti Mäntylä
Aalto University

Martti Mäntylä – Back in business!

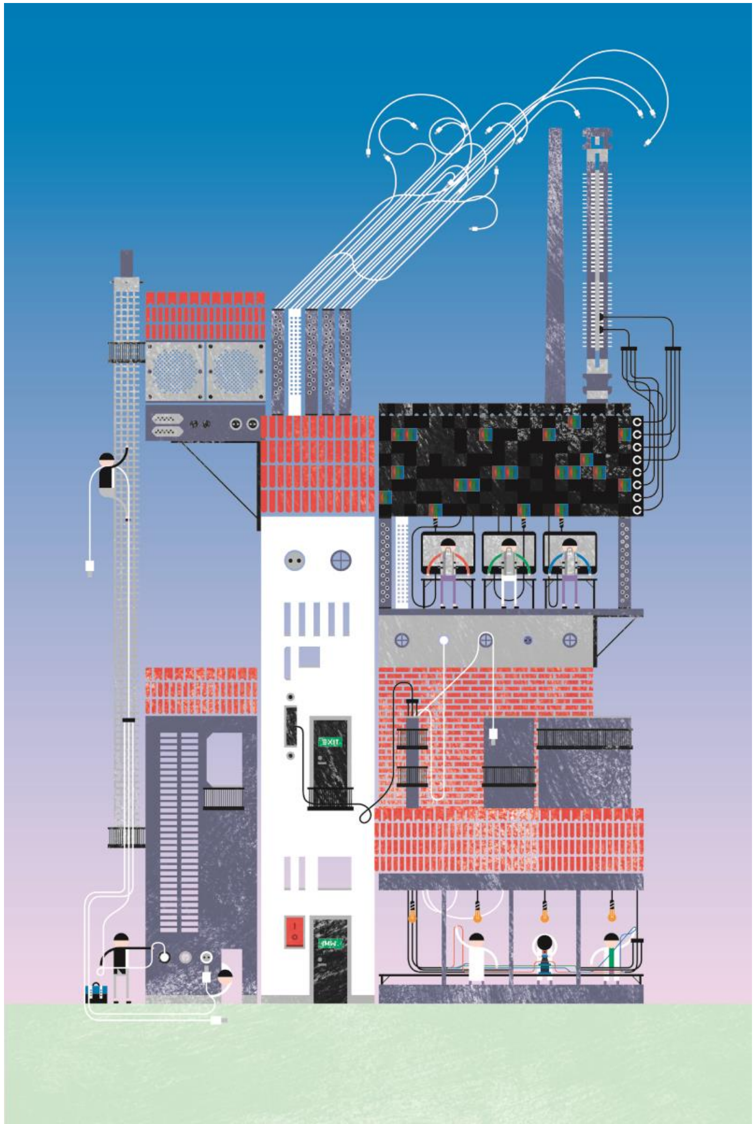
- Professor of Information Technology (Enterprise Systems), TKK & Aalto University 1987-
- Chief Strategy Officer, EIT ICT Labs 2009-2013
- Director, Helsinki Institute for Information Technology 1999-2008

- Since 2014, catalysing Aalto's activities in Industrial Internet



Aalto Industrial Internet Campus

Innovation and *Encounters* backed up by *Research* and *Education*



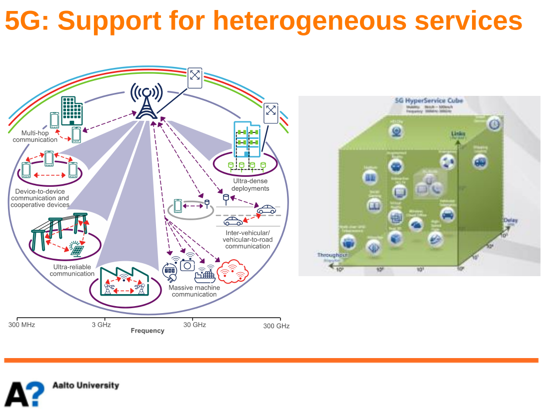
http://aiic.aalto.fi

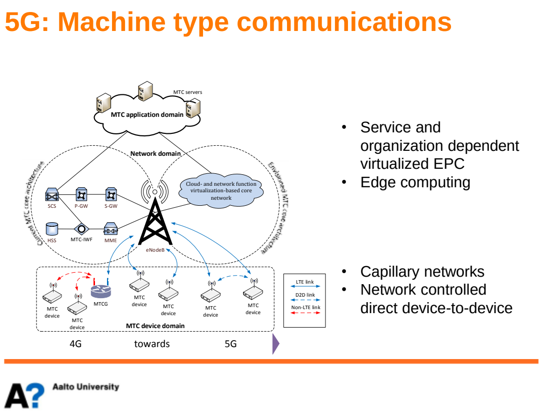
5G, Please Meet Industrial Internet

Aalto University

5G as an Industrial Internet Platform?

- Today, 4G/LTE architecture manages 2 billion mobile devices in a multiple actor environment, including sharing of business data across operators
- Can 5G provide a management architecture for 20 billion smart devices, including setting up "overlays" for industrial firms for data management and "joint clouds" for controlled data sharing across companies?
- If "yes", what should we do about it?





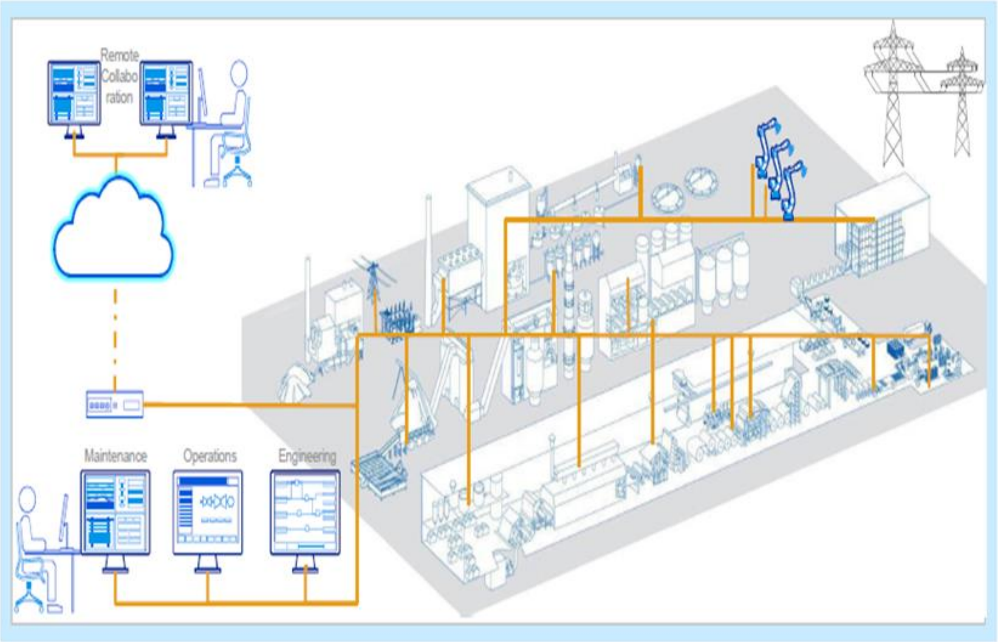
Business Case: Forest Industry

Share, analyze and utilize cross-enterprise data from a production line for win-win-win solutions

- Shared benefits across production life-cycle in
  - Engineering
  - Operations
  - Maintenance

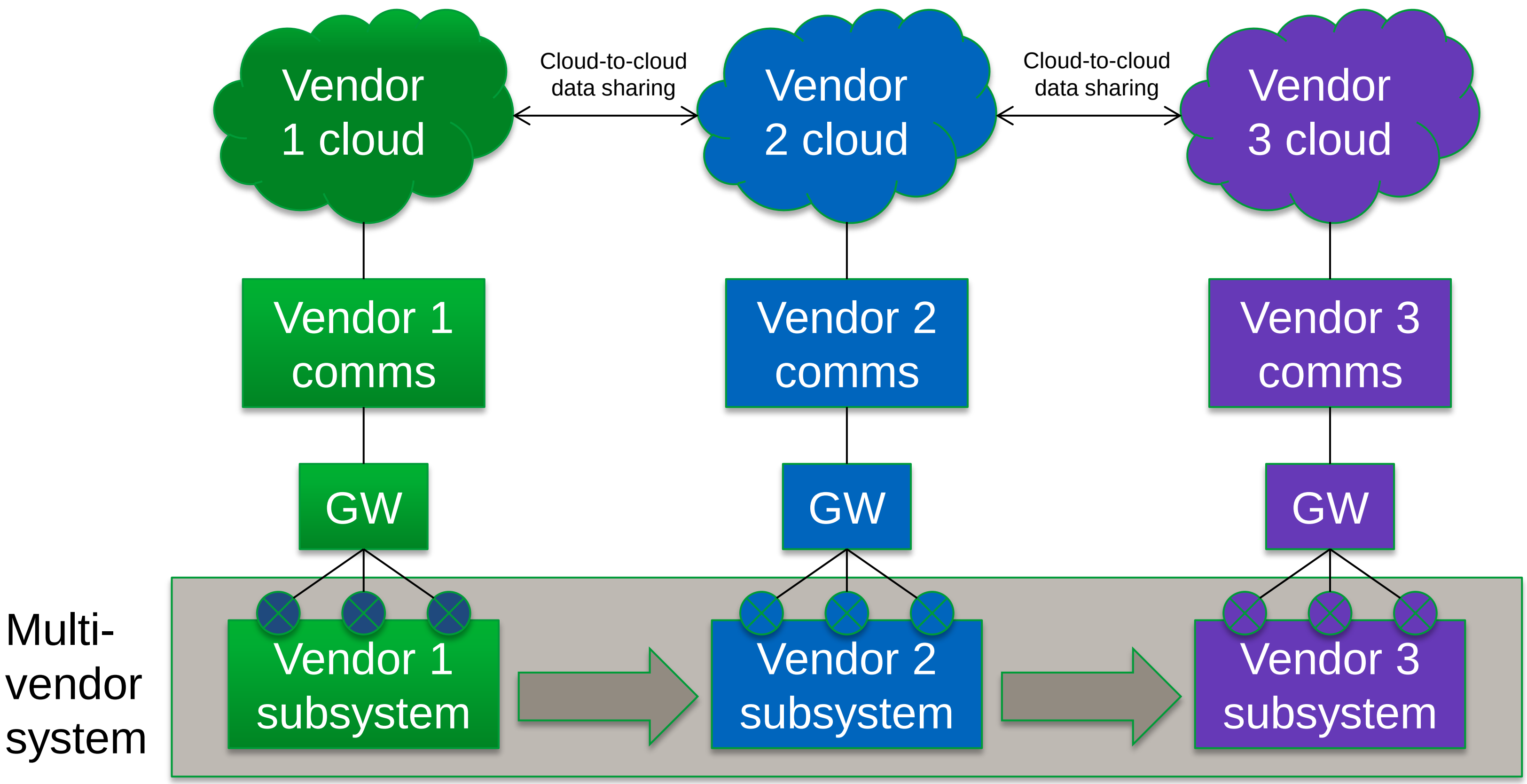
- Key characteristics of the solution
  1. Real-time data
  2. Mobile & remote operations
  3. Predictive actions
  4. Increased automation

- The scope covers all major functional units of the selected production line

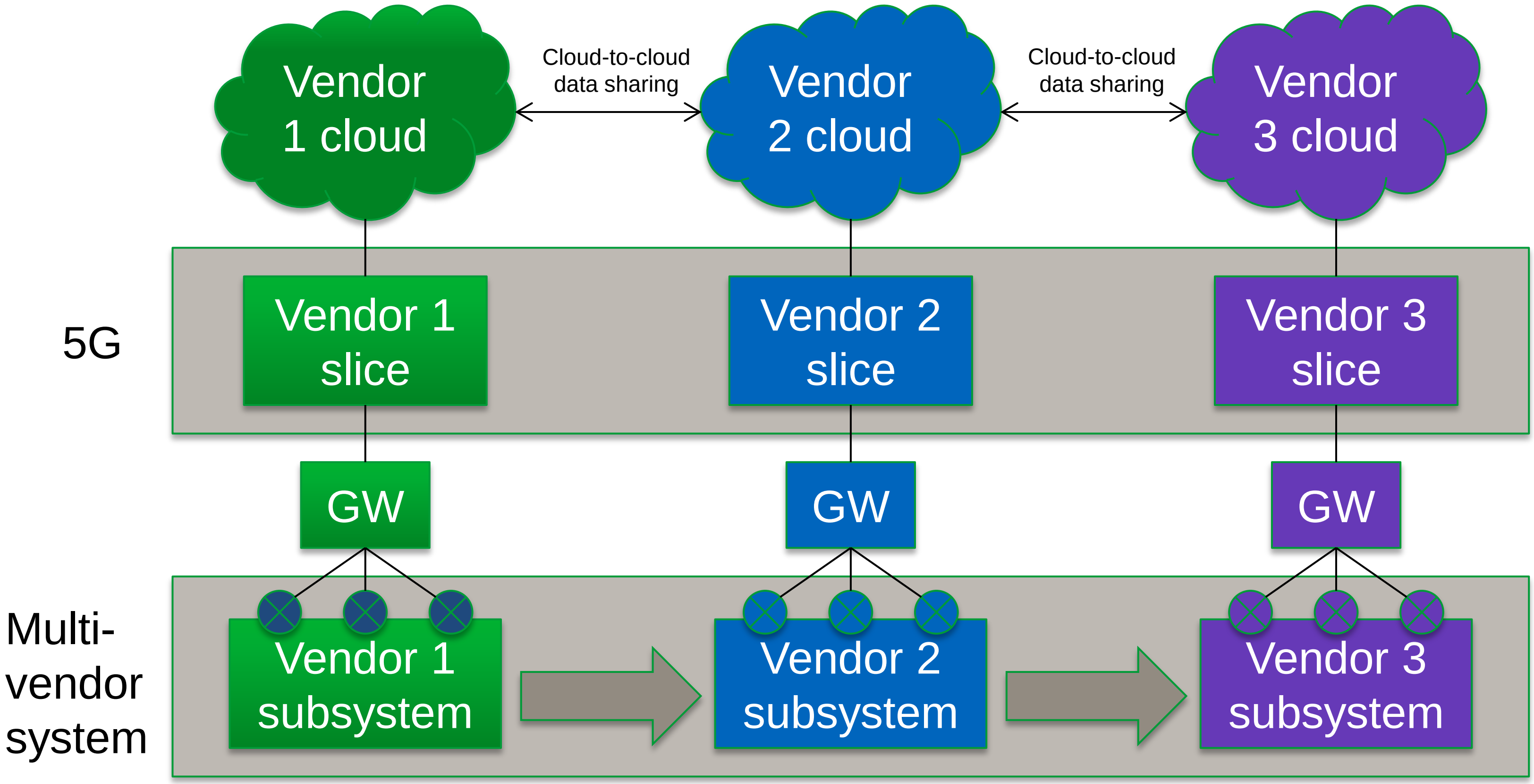


Open the sensor data of machines from a selected production line to boost operational innovations for all stake holders.

Present: Vertical silos



Future 1: Shared communications platform



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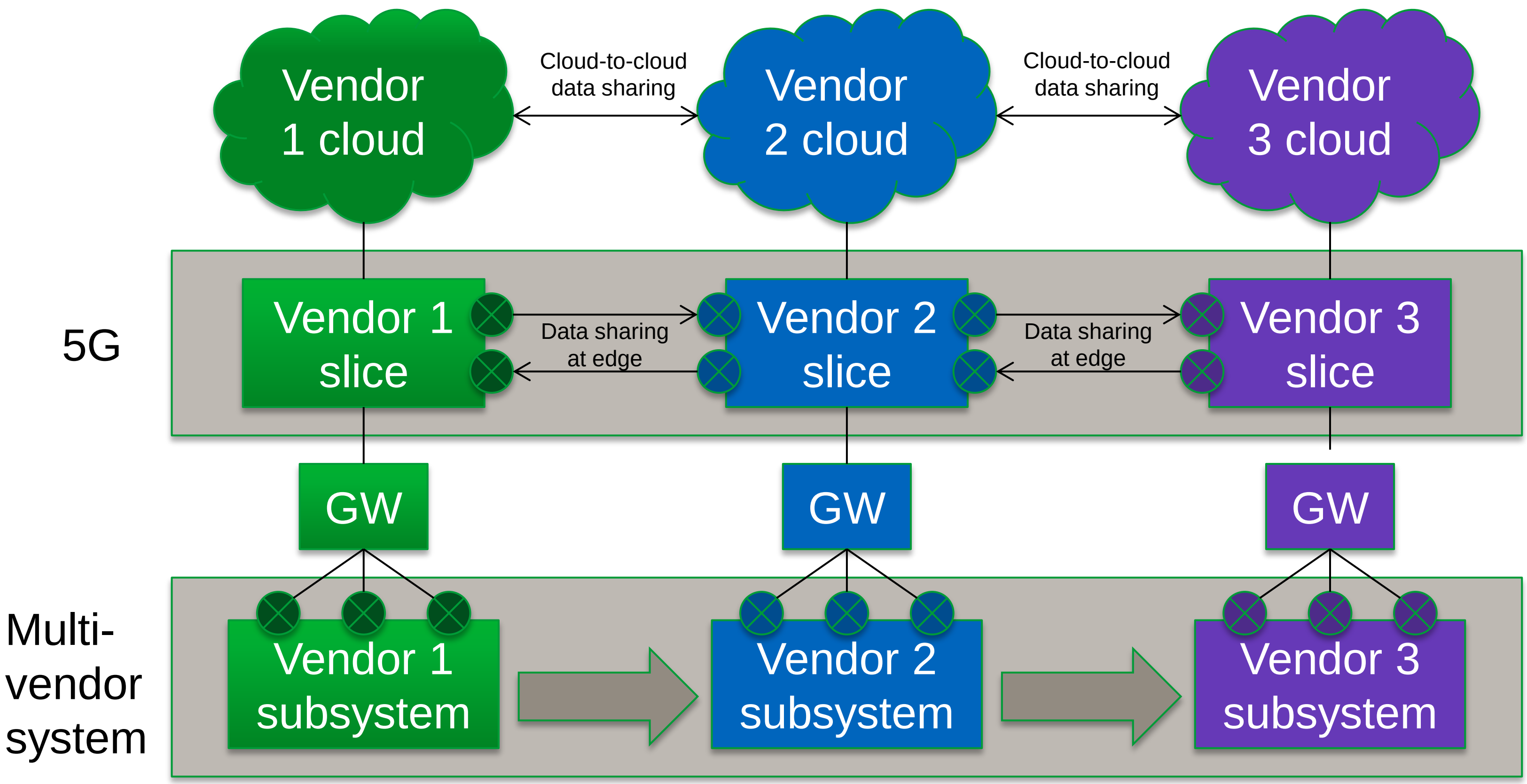
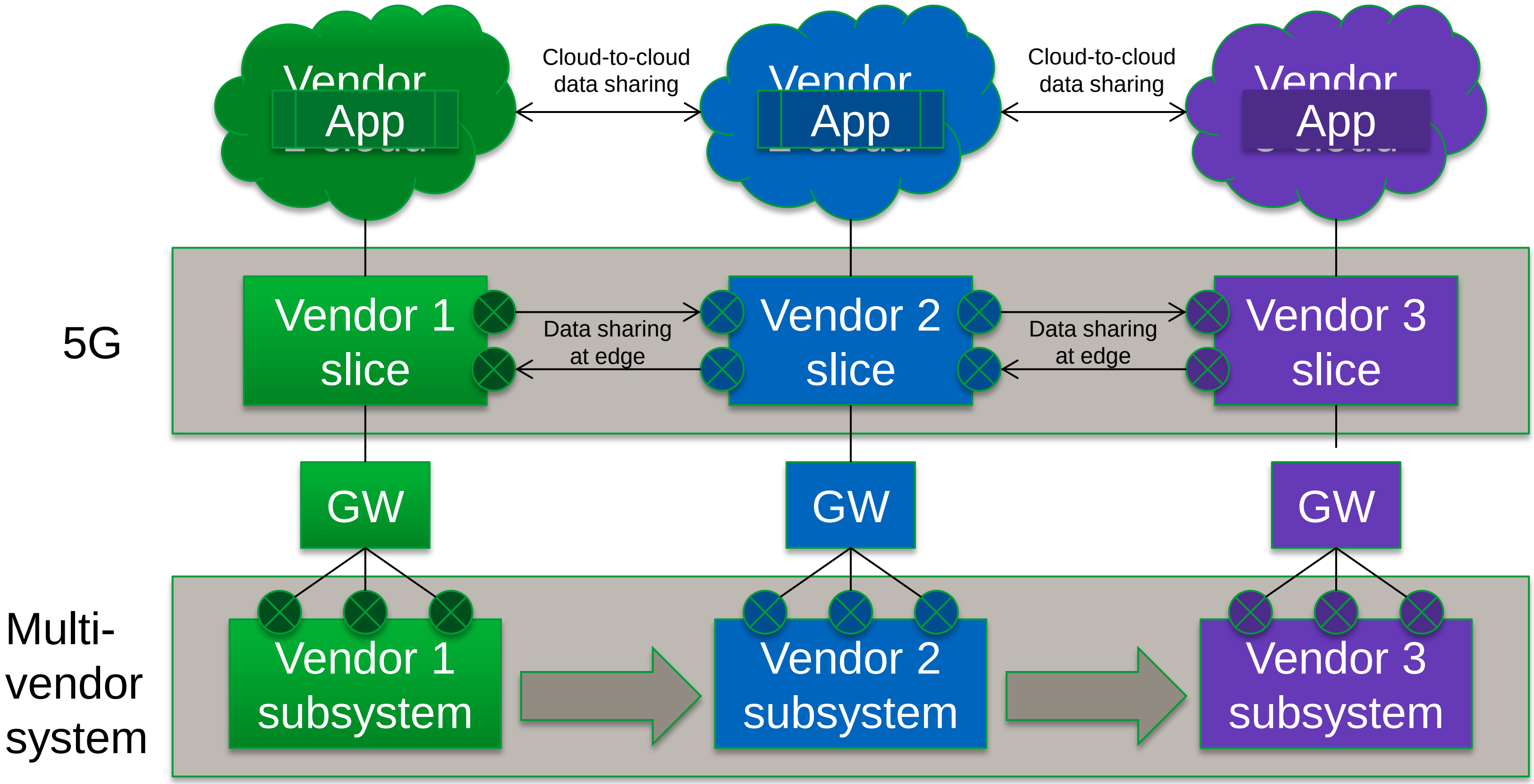
Future 2: Shared communications platform with data sharing at edge



Future 3: Client applications at edge



5G@II Project

Aalto University

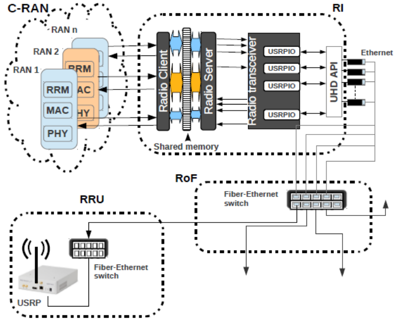
5G@II project

- Create a management system embedded in the 5G architecture that will support
  - secure management of the smart devices
  - scalable and secure data collection and storage on the basis of 5G network slicing
  - policy-based digital contracting, digital service creation and management
  - trustworthy data sharing using models rather than data itself.
- Pilot the system by combining the AIIC platform http://aiic.aalto.fi/en/ and TAKE-5 experimental 5G network (http://take-5g.org/) and running concrete experiments based on industrially relevant use cases.

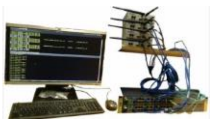
TAKE-5

5G research platform @Aalto

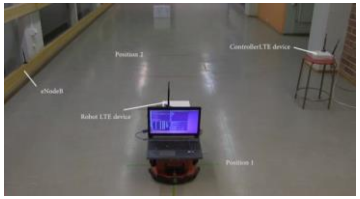
- Aalto TD-LTE testbed
  - Implementation of TD-LTE tesbed (Rel. 8) on general purpose processors and non-real-time operation system
    - Over 30 000 lines of C++ code
    - PHY and limited set of RRC and MAC functions
  - Cloud-RAN setup
    - Base station can run on virtual server
  - Flexible spectrum use
    - Can interact with Farispectrum geo-location data base
    - TVWS operation
  - DAS implementation
    - Antenna port selection
    - Open loop transmit diversity
  - D2D implementation
    - Network controlled D2D
    - Reliable D2D links
    - Underlay with IC
    - Mode selection
  - MTC MAC implementation
    - Compressive sensing based MAC with IC



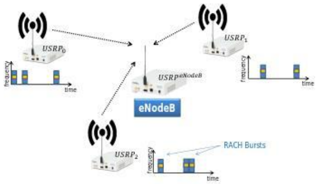
Cloud RAN architecture



eNodeB and RRU



D2D Robot control demo

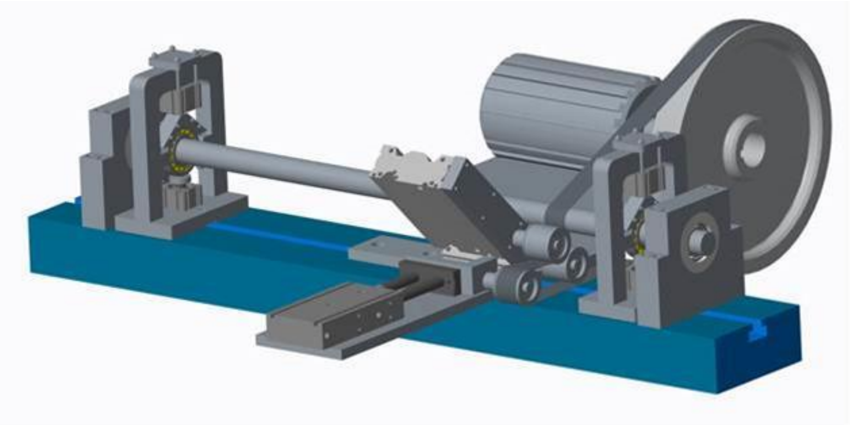


MTC MAC demo

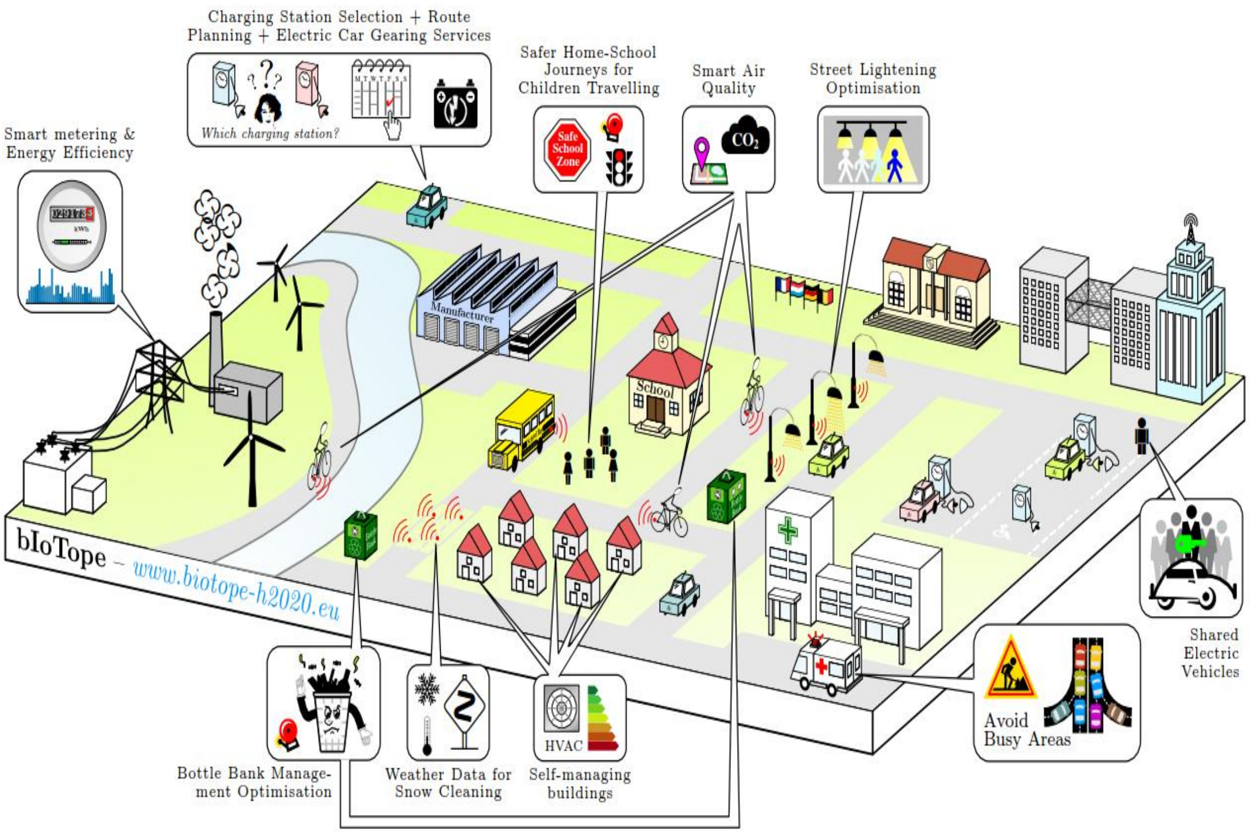
DAS demo

AIIC experimental platforms

- ABB: IoT instrumentation for a research apparatus for studying magnetic bearings
- Konecranes: Smart crane with extensive PLM models and IoT interfaces
- ABB et al.: Process control lab with several IoT-enabled unit processes
- ACRE: Digital campus



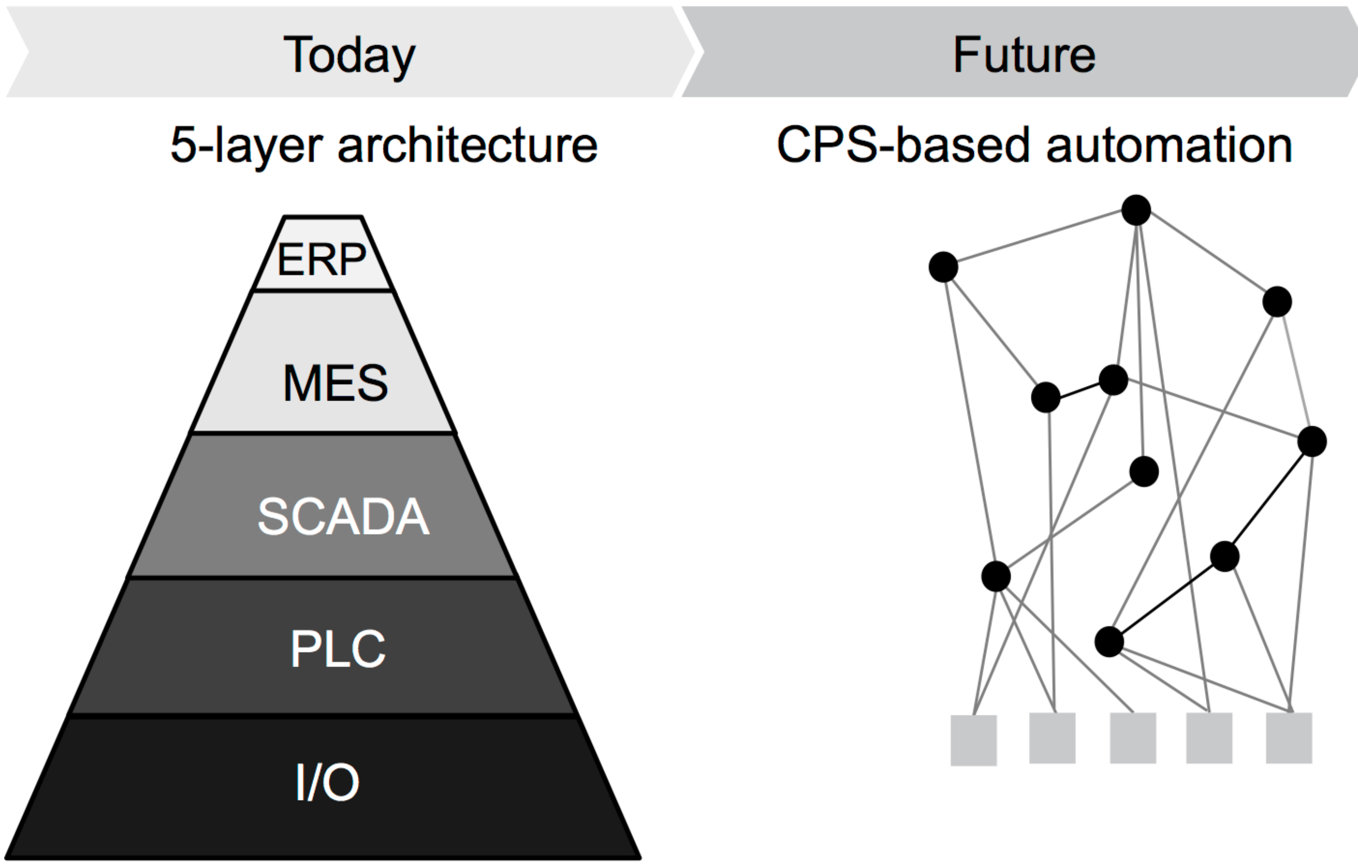
Digital campus: bIoTope project



Nomenclature

- “Factory”: shorthand for various kinds of production sites or pieces of physical infrastructure with a variety of equipment organised and managed as a whole
- “Equipment”: individual pieces of production equipment inside a factory, presently typically organised and managed with a hierarchical control structure (ERP, MES, SCADA, PLC)
  - With Industrie 4.0, the fixed hierarchical control may be replaced by a more flexible network of “components”
  - This opens the door for more flexible and agile control architecture (“control by cloud, and without ownership”)

From 5-layer architecture to autonomous cyber-physical systems



Data

- Production management data: Data on the material flow (inputs and outputs) through the factory and its equipment
- Control data: Used to control the direct operations of a factory and its equipment
- Diagnostic data: Used to monitor the performance of the operations of the factory and its equipment
- Engineering data: Lifecycle engineering data on the factory and its equipment (incl. design data, configuration data, maintenance histories, data on embedded software where relevant)
- Orthogonal categories of the above:
  - Personal data: Data related to persons operating the factory
  - Company data: Data related to the identity of the stakeholder(s)

Stakeholders / domains of governance

- Factory "owner"
- Factory operator (if distinct from owner)
- Shop floor operator
- Equipment provider
- Supplier(s) and customers
- Service providers
  - Incl. maintenance, engineering services
- Regulators, certification authorities
- Financial institutions
- Public domain

Use cases

- Factory control
  - Local / remote
- Factory monitoring
- Fleet management
- Digital twin
- Intelligent mobility

Factory control

- Enable control of factory equipment for industrial process optimization
- Local: E.g., private 5G network inside factory site
- Remote: E.g., network slice for data transmission between different production sites and other parties
- Stakeholders:
  - Factory owner: needs full access
  - Equipment providers: must grant access to the control features

Factory control

- 5G issues
  - Spectrum management
  - Latency (Especially to enable “remote control” by leveraging cloud-based approach)
    - On-demand provisioning of some "control" features at the edge of the network
  - Dynamic network and service chaining
  - Robustness and availability
  - Cyber security
  - Lifecycle management
    - New equipment, new control software versions, …
    - Esp. scenarios where equipment from many vendors needs to be managed and controlled in a single system

Factory monitoring

- Provide data for monitoring the performance of the factory and its equipment
  - (Some) control data, diagnostic data
  - Collect historical performance data for analysis and assessment
- Stakeholders:
  - Factory owner: full view
  - Equipment provider: partial view related to the specific piece of equipment (plus potentially relevant other data related to the use context) -> **fleet management**
  - Other stakeholders: e.g., regulative body, financial institution, factory supplier, factory customer, factory service provider

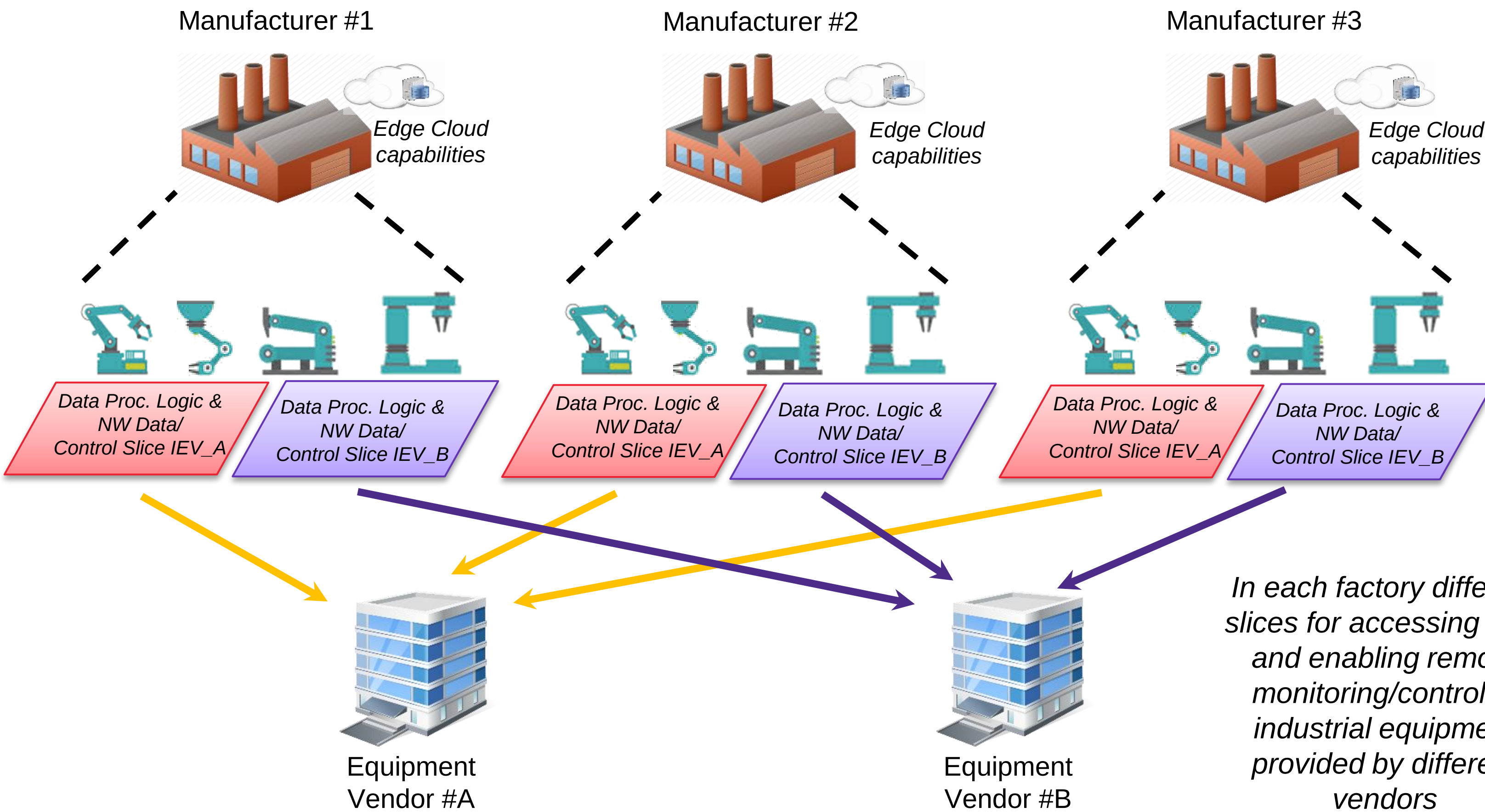
Factory monitoring

- 5G issues
  - How to provide several parallel views to the underlying factory data flows corresponding to the needs of various stakeholders and respecting the confidentiality requirements of each?

Fleet management

- Remote management of equipment by its provider
  - Diagnostics / predictive maintenance: Collect diagnostic data for fault prediction and assessment, guide maintenance operations
  - Life-cycle engineering: Collect diagnostic data to study how the operations can be improved by better design, optimising the control, improving the product configuration via some update, etc.), design and deploy updates
- Stakeholders:
  - Equipment providers: access to relevant data from installed base
  - Customers: need to grant access to relevant data
- 5G issues
  - How to provide access to all installed equipment on the field while respecting the confidentiality requirements of the customers?

Remote monitoring / fleet management



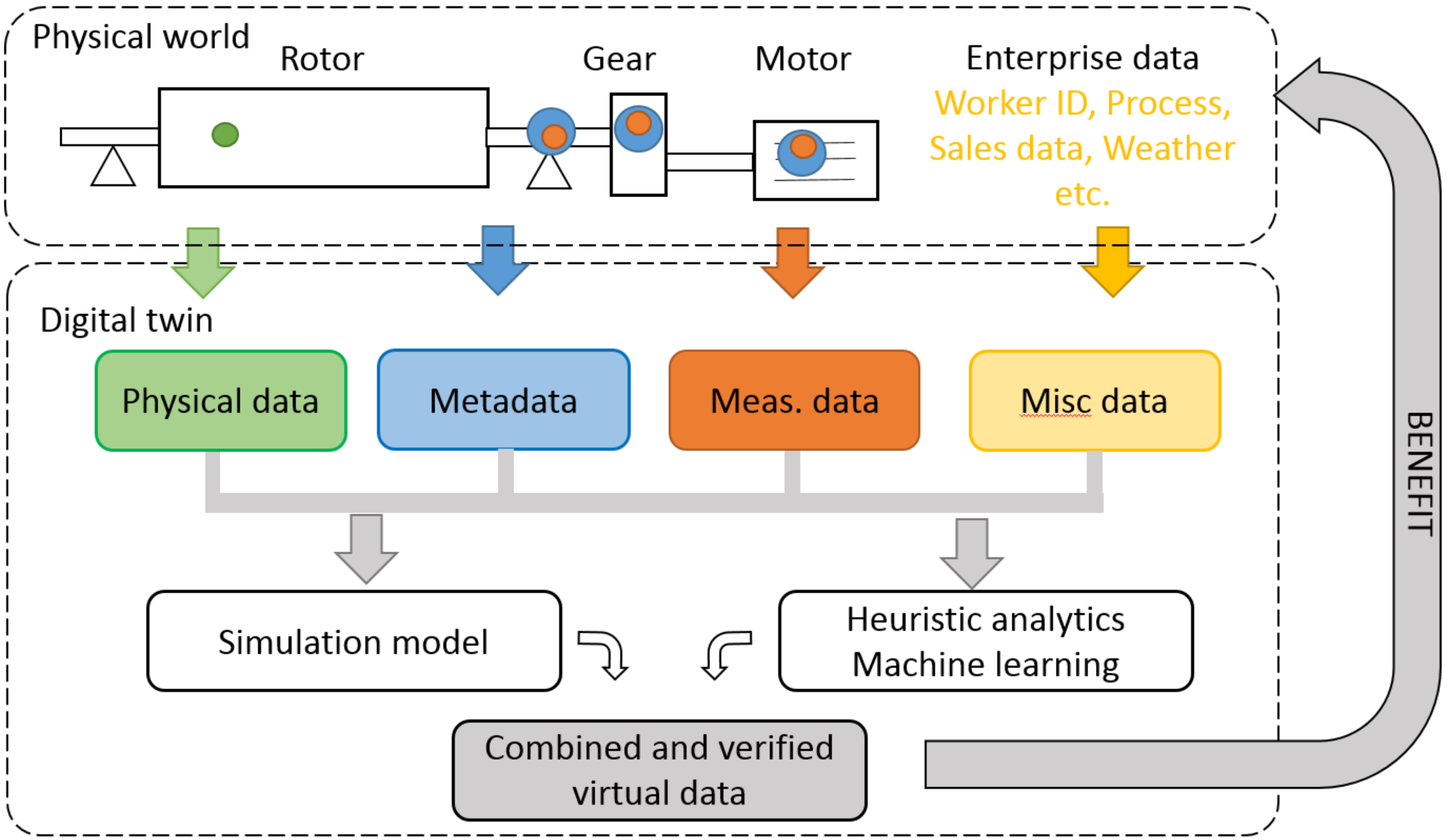
In each factory different slices for accessing data and enabling remote monitoring/control of industrial equipment provided by different vendors

Picture credit: Ivan Ferris & Tarik Taleb

Digital twin

- Build and maintain a comprehensive data repository representing a specific product instance across its whole lifecycle (design, manufacturing, installation, use, demolishing/reuse), e.g.
  - Rich design/engineering data such as simulation models and design rationales
  - Maintenance history
  - Time-series data of embedded sensor readings

Digital twin



Intelligent mobility

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News & Events

- News
- Events
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- Finland 100
- News archive +

Henry Ford Trust and Aalto University to cooperate on smart traffic research

LISTEN

02.06.2017

A networked traffic system offers possibilities to streamline traffic safety, mobility services, and traffic, especially in urban environments.

Henry Ford Trust will support Aalto University's research project on smart traffic with a four-year funding. The extent of the whole project is about 700 000 euros, of which the trust will now fund the first year and the purchase of a research car. When realised in its entirety, the trust's funding enables three four-year doctoral theses on the field of smart traffic.

The trust also annually awards grants for several Master's and other theses.

"Aalto University's interdisciplinarity is a strength in researching future technologies and their applications. The study of smart traffic and mobility is closely tied to digitalisation, new energy solutions, and built environment, which are our strengths", says Dean **Gary Marquis**.

"Committed research, building networks, international cooperation, and systematic utilisation of information multiply the effectiveness of the investment", states **Hannu Pärssinen**, the chair of the board of Henry Ford Trust.

Use cases vs. AIIC experimental platforms

	Smart crane	Process plant	Building mgt
Factory control	M2M scenarios with strict latency requirements	Remote control scenarios with strict latency requirements	System-level control of devices from multiple vendors Equipment life-cycle management
Factory monitoring /fleet management	Managed access to relevant data to the equipment provider Partial access to relevant data to other stakeholders	Managed access to relevant data to the equipment providers	Managed access to relevant data to the equipment providers
Digital twin	Data integration scenarios including sensor data	On-line simulation & control scenarios	On/off-line simulation and control scenarios

Comments and questions welcome!

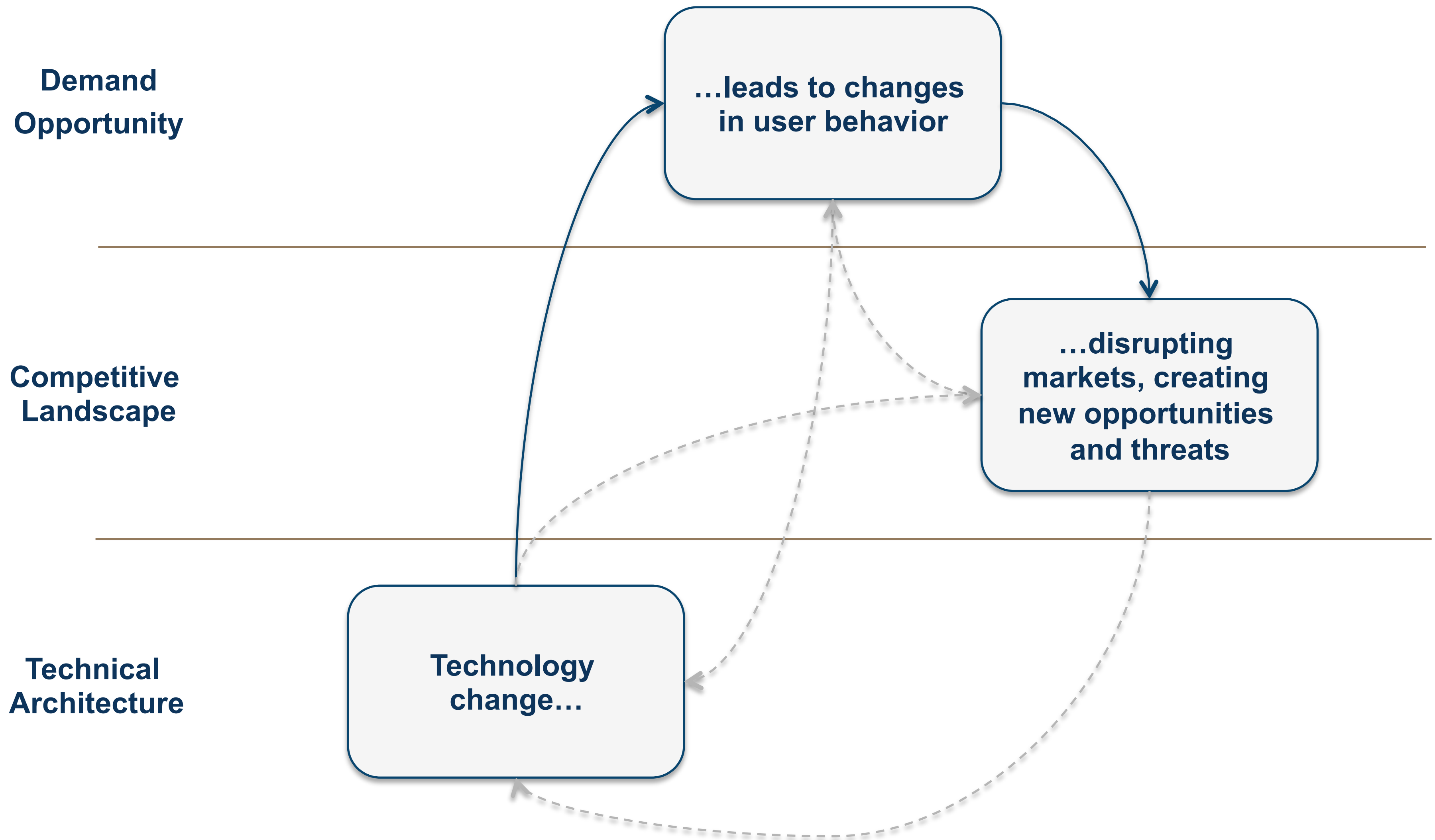
AltmanVilandrie & Company

The Transition to 5G and the Internet of Things

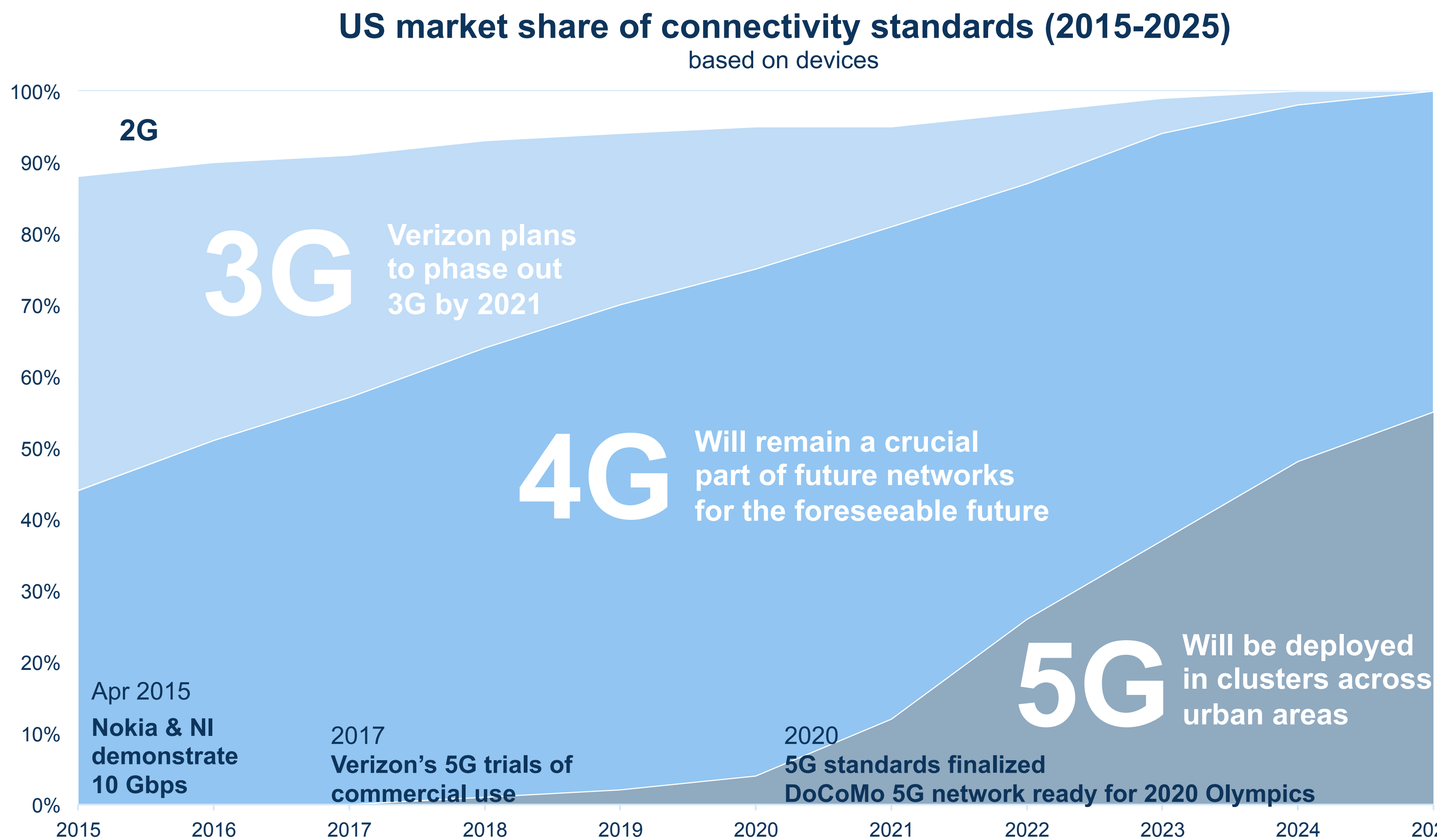
June 10, 2016

Effective strategy begins with understanding how technology evolution and changes in user behavior create new opportunities and challenges for businesses

Dynamics of Change for Technology Businesses



US wireless networks will shift from 4G LTE to 5th Generation (5G) wireless solutions over the next 5-10 years

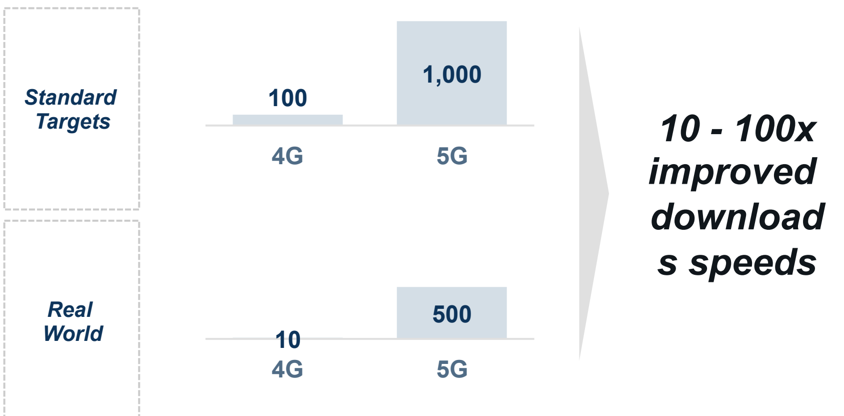


Sources: GSMA Intelligence; DoCoMo; 3GPP

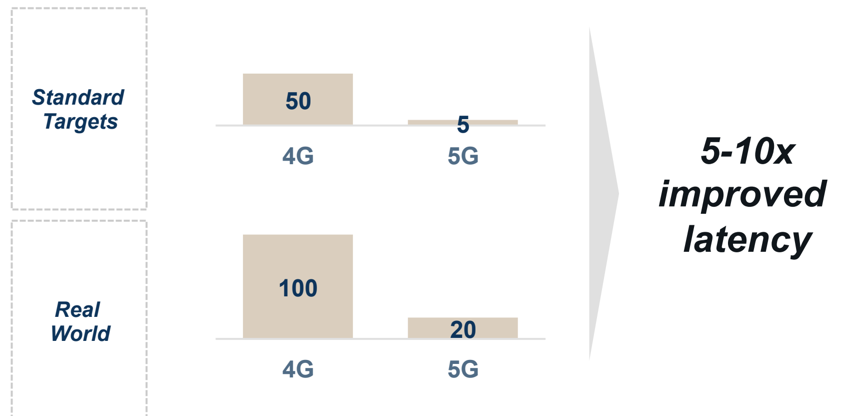
Performance of 5G vs. 4G

5G will provide a number of benefits: Super fast wireless broadband, lower latency, much greater capacity, and the ability to handle many many more devices

Avg. Download Speed *(Mbps)*



Avg. Roundtrip Latency *(milliseconds)*

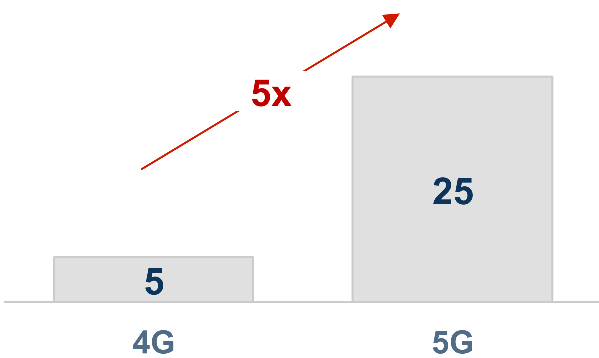


Sources: Nokia 5G Deployment White Paper; Samsung: 5G Vision;
Scenarios for 5G Mobile and Wireless Communications: The Vision of the METIS Project (IEEE Communications Magazine, May 2014)

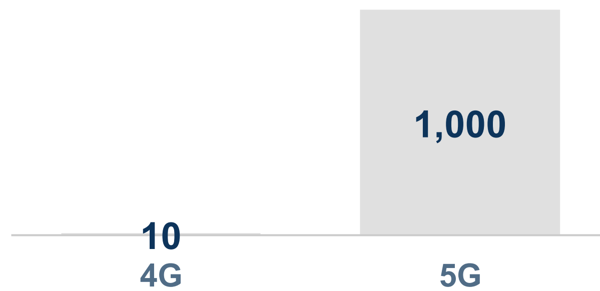
5G Economics

At first 5G will be primarily in urban and dense-suburban areas – and used for fixed wireless to deliver home broadband

Small Cell Density
(Small Cells = Macro Cell Coverage)



Throughput Capacity
(Gbps/km2)



- 5G will require many more sites to cover the same area – deployment economics will be challenging in rural areas
- But 5G also will have many times the capacity
- This makes 5G an excellent solution for urban capacity challenges
- And the high costs require new sources of revenue, making home broadband an attractive market opportunity

This is happening first in the US, ahead of standards, because of unique competitive dynamics of this market

Cable Companies (columns) / **Wireless Carriers** (rows)

	No Mobile Offer	Mobile Offer
Home Broadband	**Wireless Wins**	**Both Improve**
No Home Broadband	**Today's Market**	**Cable Wins**

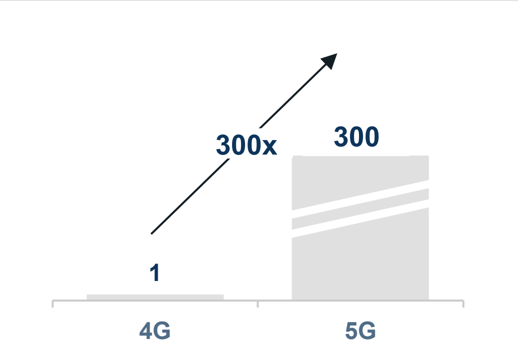
Competitive Dynamics are accelerating the move to 5G

- Wireless companies are moving into home broadband with 5G
- Meanwhile, cable companies are moving into mobile with WiFi and potentially new spectrum or partnerships
- If one moves and the other doesn't, then there is a large opportunity
- If both move, then they are still likely better off due to bundling and higher ARPUs and the opportunity to change the competitive dynamice

In the long-run, however, 5G's other benefits will help unleash the Internet of Things

5G Connectivity

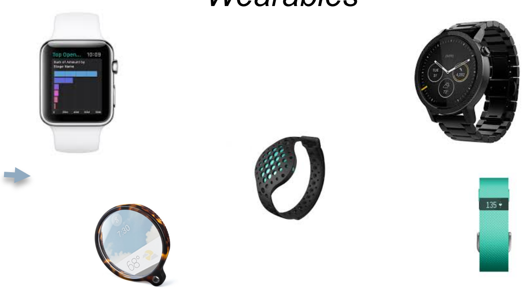
Max Simultaneous Connections per Cell
(000s connected devices)



Smartphone as 'Life Controller'

Internet of Things

Wearables



Connected Car

Connected Home

New Interaction Models

As we move from the smartphone world to the Internet of Things, new interaction models, including voice, multi-modal, and autonomy, will become much more prevalent

From → ***To***

Smartphone as 'life controller'	***Automation***	***Voice***	***Multi-modal***

Examples…

Google Now

Nest

Amazon Echo

Siri and OK Google

A handful of key players are battling over who will control this new multi-device, multi-modal user experience – and all are investing millions in these user interfaces

	Platforms / Intelligence	Distribution / Services	Devices	Apps / UI	Investment Summary
	Siri *$200M, 2014*; HealthKit 2014; ResearchKit 2015; Apple CarPlay 2015; HomeKit 2015; CareKit 2016; *3 other speech tech / personal assistant acq., $50M+*		Watch 2015	HealthKit 2014; Apple CarPlay 2015; HomeKit 2015	**$250M+, 4 deals, 7 products**
Google	android wear 2014; android auto 2015; Brillo 2015; nest *$3.2B, 2014*; Google Self-Driving Car Project; Google Assistant 2016; *1 other acq., undiscl*		GLASS 2014; nest *$3.2B, 2014*; dropcam *$555M, 2015*; Google Self-Driving Car Project; Google Home 2016; *1 other aq., undiscl.*	nest *$3.2B, 2014*; android auto 2015	**$3.8B+, 4 deals, 9 products**
amazon	amazon alexa *$250M, 1999*; 2lemetry *IoT Platform Undiscl., 2015*; safaba *Text translation Undiscl., 2015*; AWS IoT Platform 2015; Orbeus *AI image recog. Undiscl., 2015*		amazon echo 2014; Echo Dot – 2016; Amazon Tap – 2016		**$250M+, 4 deals, 5 products, strong recent hiring**
f	Parse *$85M, 2013 To be shut down 2017*; wit.ai *Undisclosed, 2015*			Moves *Fitness tracker app Undisclosed, 2014*	**$85M+, 3 deals**
SAMSUNG	SmartThings *$200M, 2014*; Connect Auto 2016		Samsung GALAXY Gear 2014; SmartThings *$200M, 2014*; Connect Auto 2016; • Home Appliances • Smart TVs	Samsung GALAXY Gear 2014; SmartThings *$200M, 2014*; Connect Auto 2016	**$200M, 1 deal, >5 products**

Implications for Accessibility / M-Enablement – initial thoughts

Likely Benefits From 5G

- Multi-model cross device and applications and user interfaces will provide **more choice and flexibility** in how customers can interact with services
- **Proactive, intelligent and context aware** applications and services will improve the user experience / make things easier to use
- **Autonomous devices and systems** will reduce time required to get value out of technology
- **Low latency and high bandwidth** will improve performance and the types of applications that can be supported

Risks from 5G

- **Inconsistent availability and capabilities** from networks and services
- **Mass market consumer services may get ahead** of healthcare, regulation, and funding options
- **Reliability of 4G and 5G** may remain inferior to 2G or wired solutions
- **Expensive hardware** for new solutions that aren't mass market

Back up…

This performance will enable a broad set of new use cases for wireless networks, including most of the key uses for home broadband services

	Applications	Key Requirements	Assessment: 4G	Assessment: 5G	Details
Today's Applications	**HD Video Streaming**	Download: 5 Mbps	✓	✓	Speed varies greatly with distance in 4G networks, but less in 5G
Today's Applications	**4K Video Streaming**	Download: 20 Mbps	✗	✓	5G's expected real world 500 Mbps will exceed requirements
Today's Applications	**Online Console Gaming**	Latency: <50 ms Reliability: >99.9%	✗	✓	5G's target is 99.999% reliability, but real world latency performance is unknown
Future Applications	**Cloud Gaming**	Latency: <50 ms	✗	✓	Unknown real world latency performance
Future Applications	**Virtual or Augmented Reality**	Latency: <10 ms	✗	uncertain	Issues may arise during peak hours or congested areas
Future Applications	**Future Household:** Simultaneous multiple 4K streams, VR, gaming sessions, etc.	Bandwidth: 100-200 Mbps	✗	uncertain	It may be possible to develop a 5G-to-the-home approach, but real world performance is key

Sources: Oculus, Twitch, Netflix, Verizon 4G LTE White Paper

5G is not a single technical innovation, but a set of advances and approaches that taken together create breakthrough performance improvement

			Capacity	Performance	Costs
Spectrum / RF	***Use of cm/mm Waves at very high frequency ~2.5GHz+***	**Enables high spatial reuse and throughput** **Key enabling tech:** ▪ Wider spectral bands ▪ Massive-MIMO antenna designs ▪ Beam-forming	✓	✓	✗
Cells	***Filtered OFDM***	**More robust signal:noise processing** reducing the need for guard bands, increasing QAM (256+), increasing bandwidth	✓	✓	✓
Cells	***Carrier Aggregation?***	**Enables use of contiguous and non-contiguous spectrum allocations** *(also used in LTE-A)*	~	✓	✓
Network Architecture	***Network Function Virtualization***	Enables **flexibility, cloud-like versatility, and software-upgradeability** of network components, reducing costs	~	✓	✓
Network Architecture	***Core Control at the Edge***	Less backhaul, lower latency, improved reliability from **local routing and CDN-like storage at the edge** of the network	✓	✓	✓

The evolution to 5G will consist of updates to the LTE standard together with new radio-access technology

Today	2016	2017	2018	2019	2020+

Release 13 Primarily LTE Enhancements *(Mar '16)*	Release 14 *(2017)*	Release 16 *2019*
▪ **Active Antenna Systems** ▪ **Elevation Beam-forming and Full Dimension MIMO** ▪ **Carrier aggregation** ▪ **Licensed-Assisted Access** ▪ **Massive machine-type comm.** ▪ **D2D communication** ▪ **Single-cell Point-to-Multipoint (SC-PTM)** ▪ **Enhanced signaling for coordinated multi-point (CoMP)**	▪ **Latency reduction:** Instant uplink access where transmissions can occur w/o prior request-grant, shorter transmission-time interval, <0.5 ms ▪ **Unlicensed spectrum:** extension of license-assisted access; support for transmissions in unlicensed spectrum ▪ **Intelligent Transportation Systems (ITS):** V2V and V2I communication ▪ **Massive machine-type communication:** OTA SW updates and P2P relays for coverage ▪ **Massive MIMO:** expanding to more than 16 antennas (currently up to 64 being explored)	▪ **Tight integration** between LTE and 5G radio access tech; beyond 'traditional' handover and may build on carrier aggregation frameworks ▪ **Ultra-lean design 'always on'** signals are kept to an absolute minimum to reduce energy consumption and interference ▪ **Multi-site connectivity for** enhanced data rates at the edges

5G and IoT - Separating Hype from Promise

HENNING SCHULZRINNE

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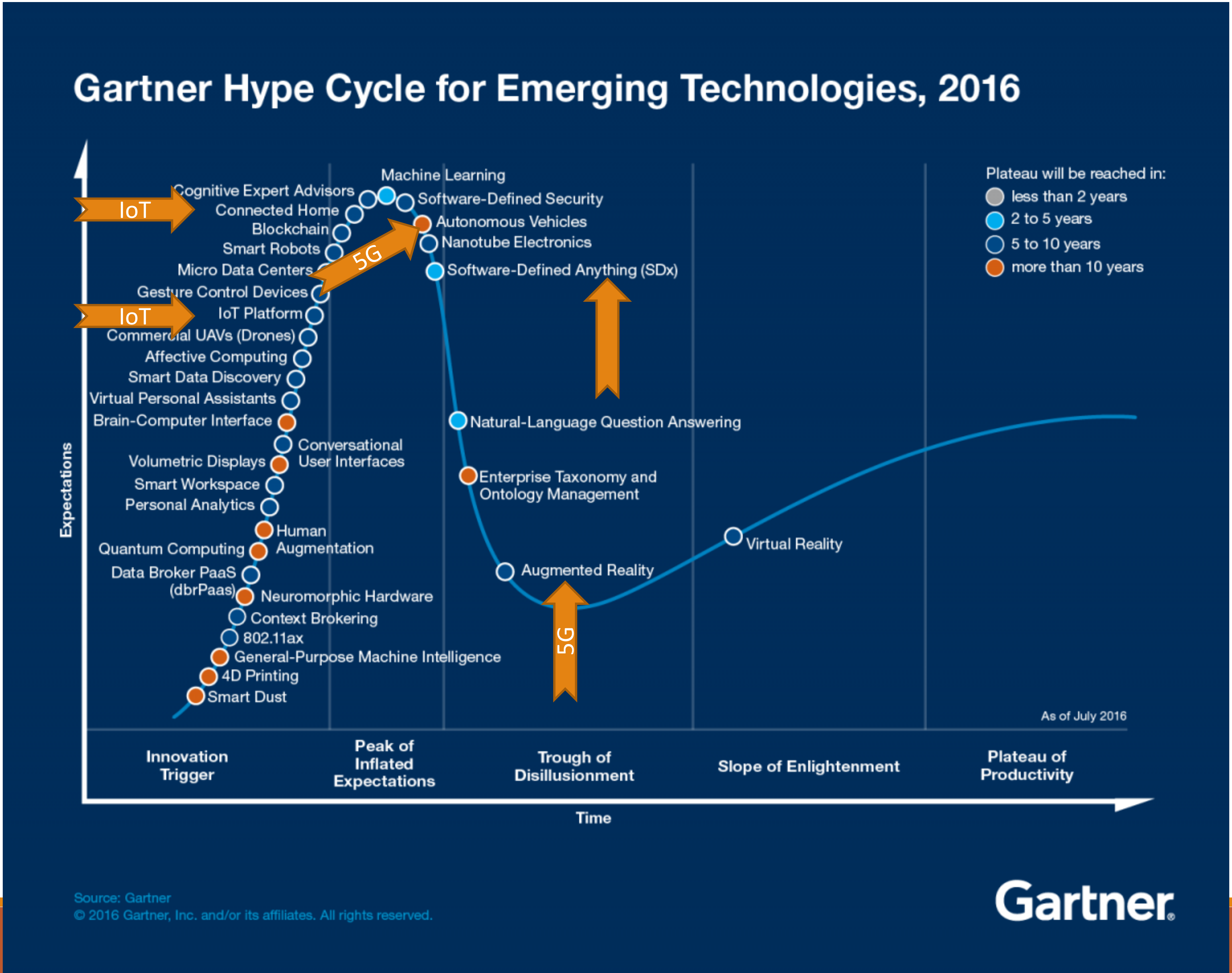

Gartner Hype Cycle for Emerging Technologies, 2016
Expectations
IoT
IoT
5G
5G
Machine Learning
Cognitive Expert Advisors
Software-Defined Security
Connected Home
Autonomous Vehicles
Blockchain
Nanotube Electronics
Smart Robots
Micro Data Centers
Software-Defined Anything (SDx)
Gesture Control Devices
IoT Platform
Commercial UAVs (Drones)
Affective Computing
Smart Data Discovery
Virtual Personal Assistants
Brain-Computer Interface
Natural-Language Question Answering
Conversational User Interfaces
Volumetric Displays
Enterprise Taxonomy and Ontology Management
Smart Workspace
Personal Analytics
Human Augmentation
Quantum Computing
Virtual Reality
Augmented Reality
Data Broker PaaS (dbrPaas)
Neuromorphic Hardware
Context Brokering
802.11ax
General-Purpose Machine Intelligence
4D Printing
Smart Dust
Plateau will be reached in:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
As of July 2016
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
Time
Source: Gartner
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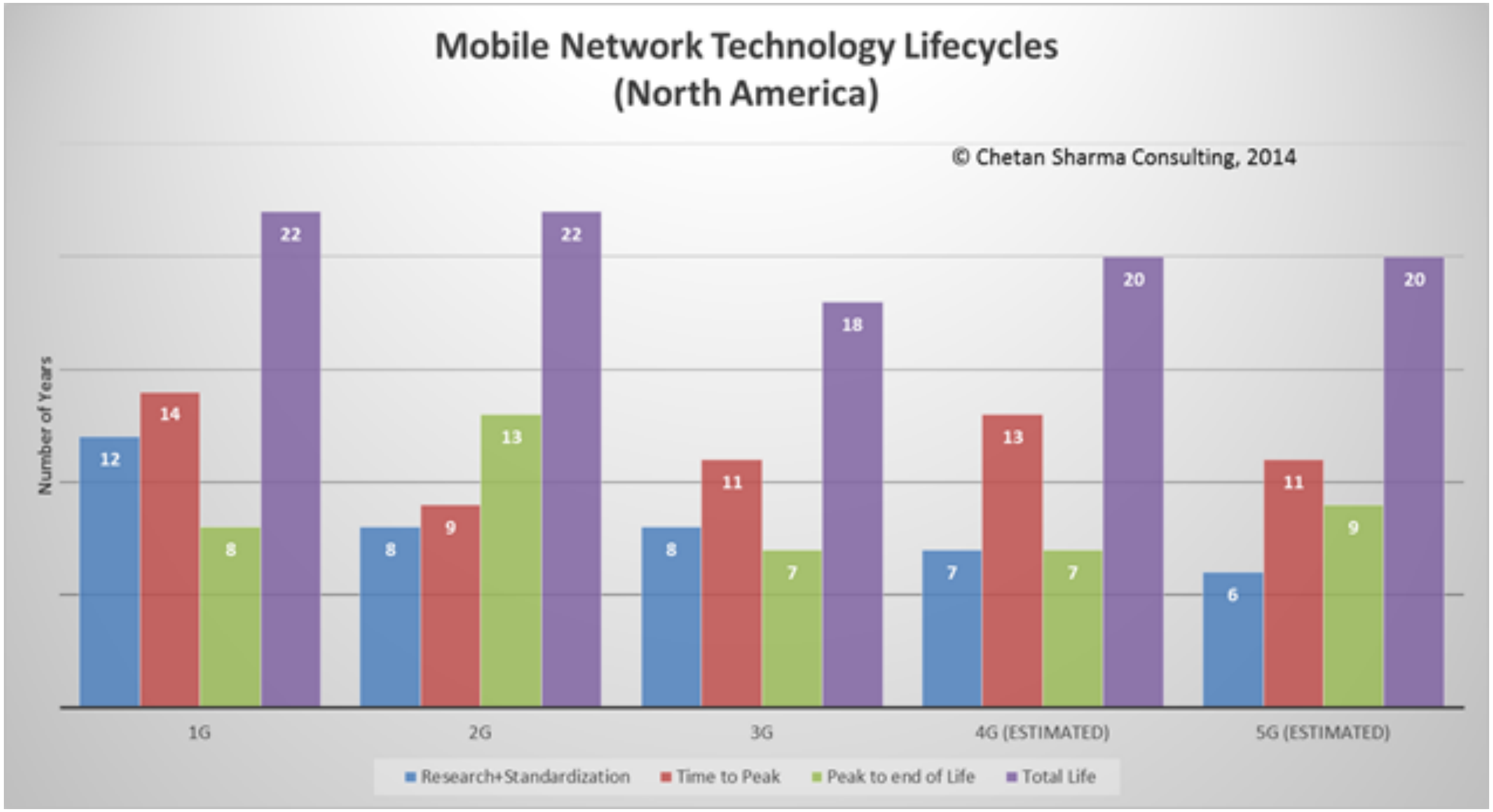
Gartner.

Design for 20 years



Generations are distinct

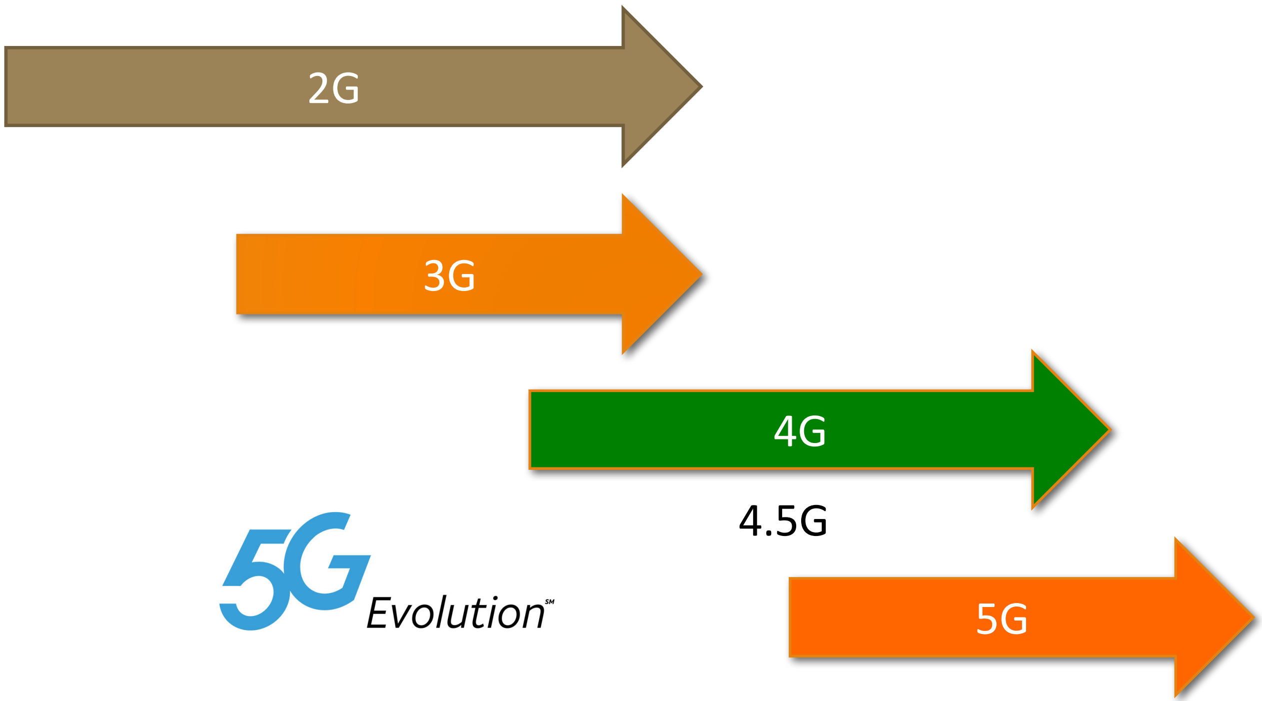
Talking a different language

	Maturists (pre-1945)	Baby boomers (1945-1960)	Generation X (1961-1980)	Generation Y (1981-1995)	Generation Z (Born after 1995)
Formative experiences	Wartime rationing Rock'n'roll Nuclear families Defined gender roles – particularly for women	Cold War 'Swinging Sixties' Moon landings Youth culture Woodstock Family-orientated	Fall of Berlin Wall Reagan/Gorbachev/Thatcherism Live Aid Early mobile technology Divorce rate rises	9/11 terrorists attacks Social media Invasion of Iraq Reality TV Google Earth	Economic downturn Global warming Mobile devices Cloud computing Wiki-leaks
Percentage in UK workforce	3%	33%	35%	29%	Employed in either part-time jobs or apprenticeships
Attitude toward career	Jobs for life	Organisational – careers are defined by employees	"Portfolio" careers – loyal to profession, not to employer	Digital entrepreneurs – work "with" organisations	Multitaskers – will move seamlessly between organisations and "pop-up" businesses
Signature product	Automobile	Television	Personal computer	Tablet/smartphone	Google glass, 3-D printing
Communication media	Formal letter	Telephone	E-mail and text message	Text or social media	Hand-held communication devices
Preference when making financial decisions	Face-to-face meetings	Face-to-face ideally but increasingly will go online	Online – would prefer face-to-face if time permitting	Face-to-face	Solutions will be digitally crowd-sourced

Source: Barclays, University of Liverpool

land line | 2G | 3G | 4G

Generations overlap



Generational surprises

Generation	Expectation	Surprise
2G	better voice quality (“digital!”)	SMS
3G	WAP	web
4G	IMS	YouTube, WhatsApp, notifications
5G	IoT (low latency)	?

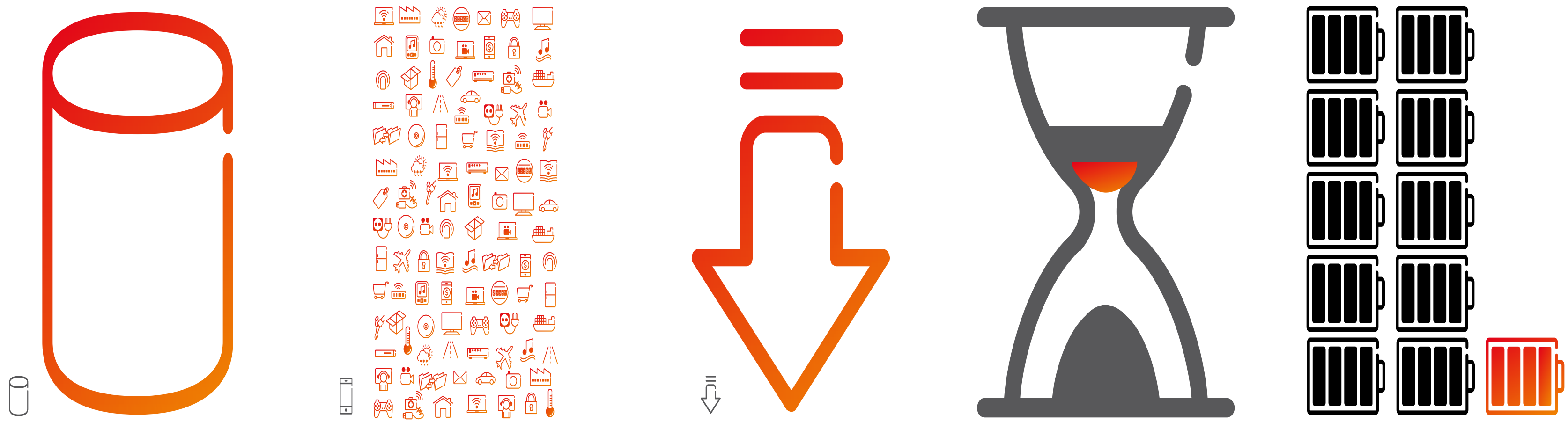
underestimated cost and fixed-equivalence as drivers

Lessons, in brief

Experience	Lessons
VoLTE, IMS	avoid complexity avoid entanglement plan intercarrier interfaces
Wi-Fi	don’t trust the RAN/AP
disaggregation of functions	clear & simple interfaces don’t assume trust between elements
app stores	keep it application-neutral
FTTH, backhaul cost	re-use backhaul where you can find it

METIS Technical Objectives

1000x data volume	50/500 B devices	Up to 10Gbps	Few ms E2E	10 years



1000x higher mobile data volumes	**10-100x** higher number of connected devices	**10-100x** typical end-user data rates	**5x** lower latency	**10x** longer battery life for low-power devices

METIS, "Toward a 5G Mobile & Wireless System Concept"

2G → 3G → 4G → 5G ➔ increasing number of technology components

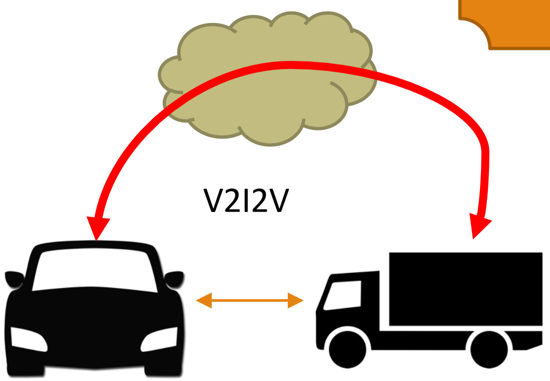
5G is a systems standard

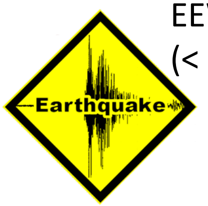
Technology component	**Proposed application**	**Less exciting, but likely**
mmWave	10 Gb/s user rates	capacity in stadiums fixed wireless?
edge computing	IoT	video caching
M2M	billions & billions of devices! autonomous vehicles!	electric meters
1 ms latency	autonomous vehicles!	keep it application-neutral
slicing	QoS	test networks, VPNs

GENI

5G low latency

one-to-many!

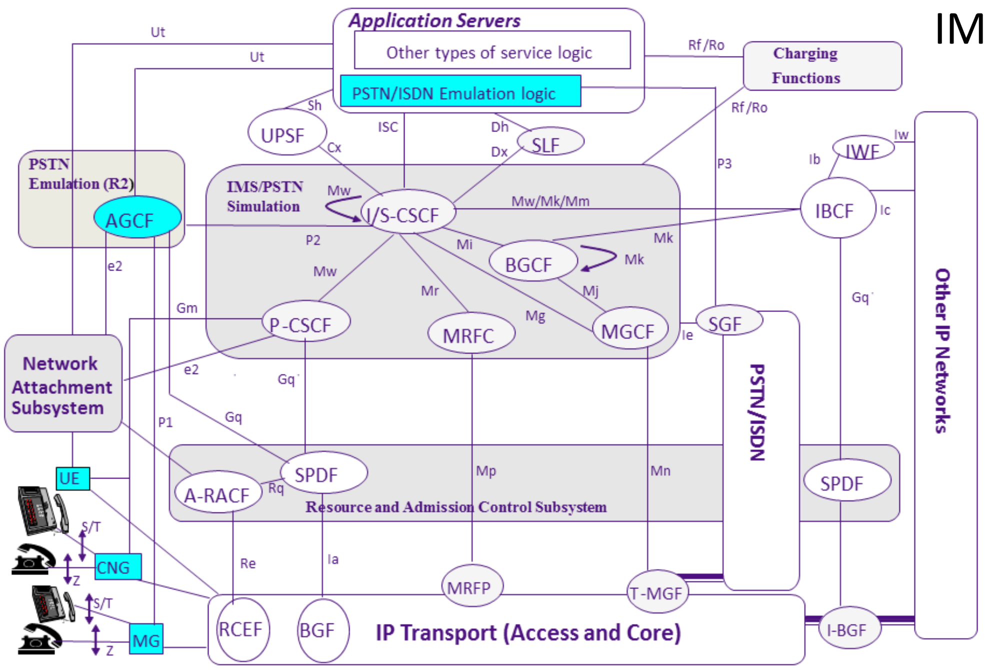




EEW
(< 5 s)

Complexity kills

IMS



Long-range networks

FEATURE	LTE Rel 13	Combined Narrow Band (NB) and Spread Spectrum (SS) (Semtech)	Cooperative Ultra Narrow Band (Sigfox)	Narrow Band M2M Clean Slate (Huawei/ Neul)
Bandwidth	1.4 MHz	400 Hz to 12.8 KHz NB and 200 KHz SS UL / 3.2 KHz to 12.8 KHz DL	160 Hz UL / 600 Hz DL	2 or 3.75 KHz UL / 15 KHz DL per channel
UL Data Rate	TBD	122 bps – 7.8 Kbps	160 bps / 600 bps	200 bps to 45 Kbps
Range / MCL	155.7 dB (24 dBm Tx Pwr)	164 dB (20 dBm TX Pwr)	164 dB (24 dBm Tx Pwr)	162 dB (24 dBm Tx Pwr)
Broadcast/Multicast	Yes	Yes	No	No?
Duplex	Full/Half Duplex (FDD)	Full-Duplex	Full Duplex	Full-duplex
Synchronization	Yes	Yes	No	Yes

IoT requirements

Application	Range	Mo-bility	Device characteristics	Service characteristics	Suitable networks
• Connected car • Fleet management • Remote health monitoring	~1000m	Yes	Rechargeable battery	Managed service, highly secure	• Cellular • Satellite
• Smart metering • Parking meter	~1000m	No	Low rate, low power, low cost	Managed service	• Cellular • Dedicated network
• Hospital asset tracking • Warehouse logistics	~100m	Yes	Low rate, low power, low cost	Enterprise-deployed	• WiFi • RFID
• Industrial automation • Home automation	~10m	No	Low rate, low power, low cost	Subscription-free	• Zwave • Zigbee • Wifi • Powerline
• Personal activity • Local object tracking • Point of sale	~1m	No	Low rate, low power, low cost	Subscription-free	• Bluetooth • NFC

Wide-area Wireless Communication Challenges for the Internet of Things
Harpreet S. Dhillon, Howard Huang, Harish Viswanathan

Niche networks persist

short range

ZigBee®

low energy; mesh

Bluetooth®

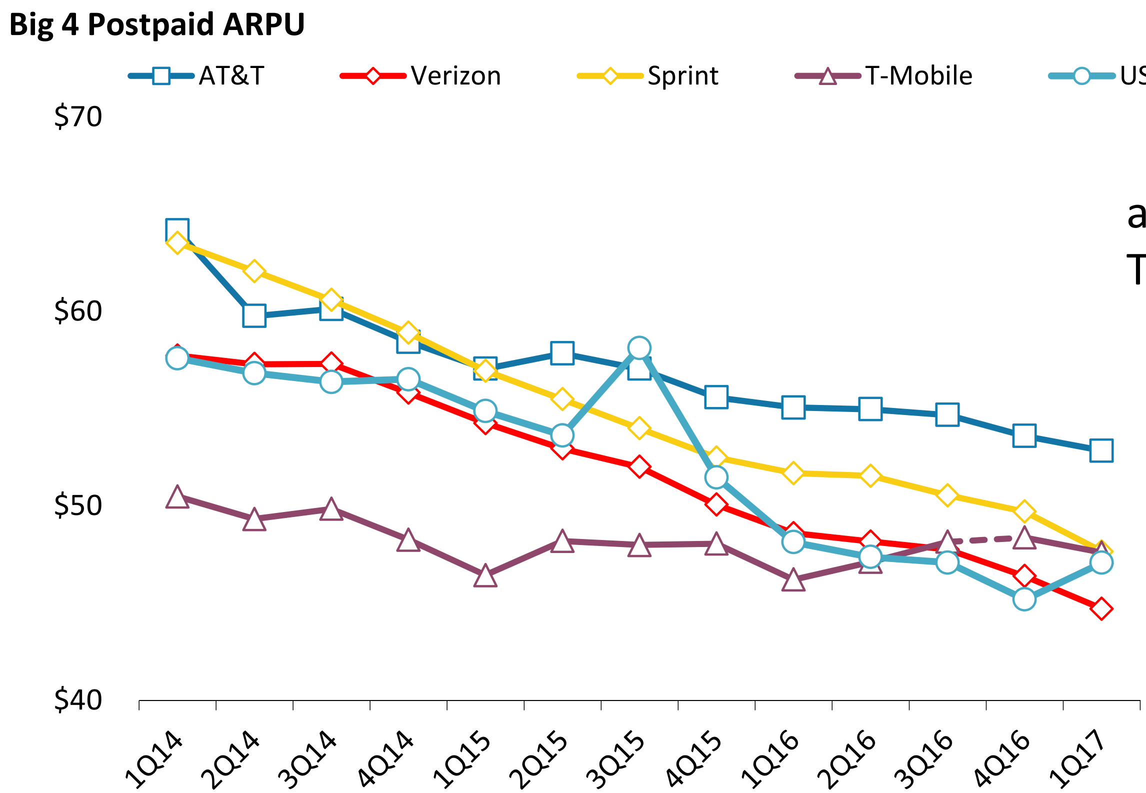
ubiquity; low cost

tries to usurp niche

WiFi™

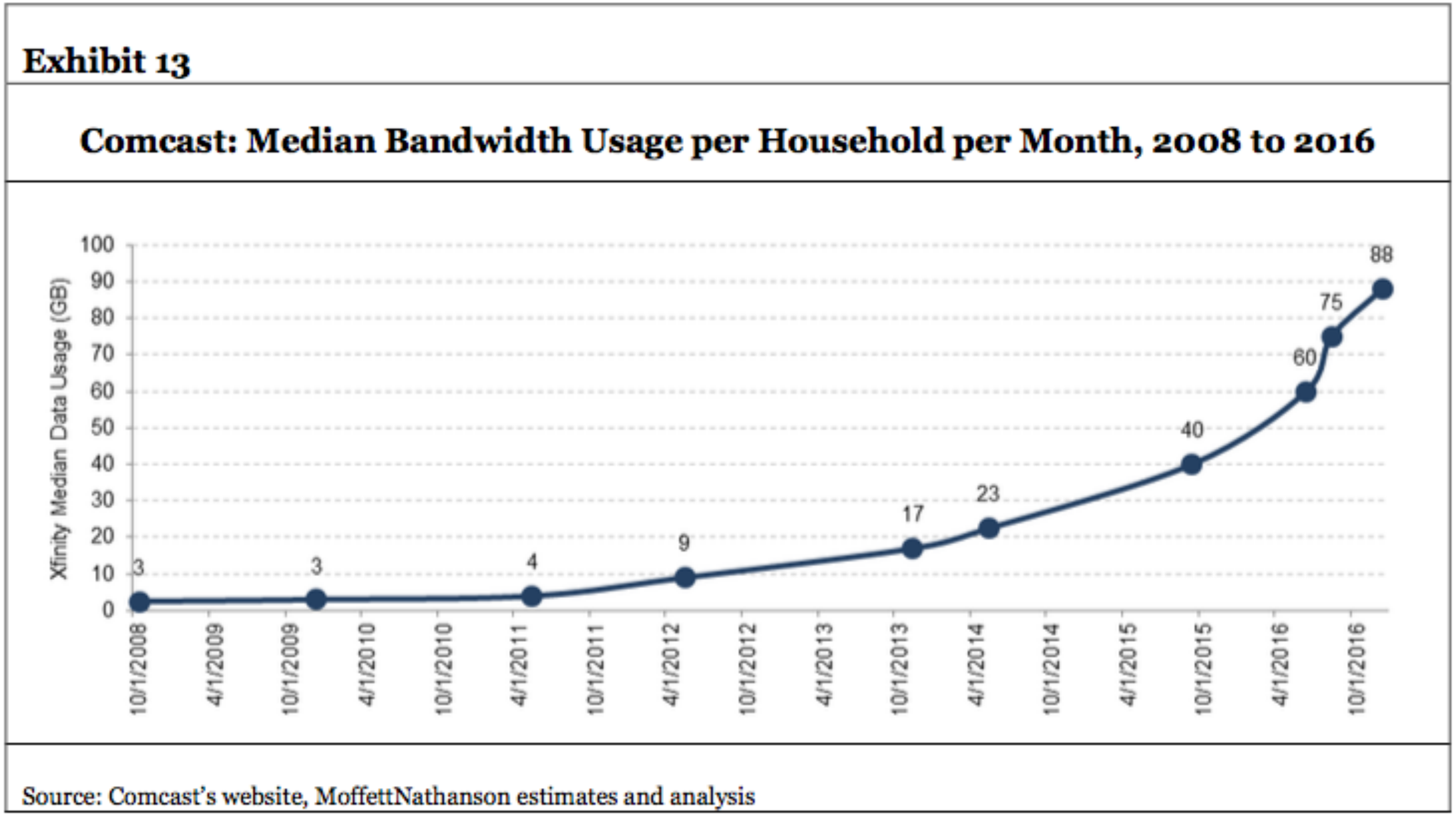
speed; public APs

What's the economic case for 5G?



avg. about 2.1 GB/month
T-Mobile: 10 GB tethering

Cord-cutting for broadband?



How can 5G be cheaper by GB?

Backhaul is major cost factor

- “Backhaul costs represent almost 6% … of a wireless carrier total operating expenses (OPEX) and 30% of total network costs.”

Re-use existing fiber to residential users

- Requires cooperation of cable/FTTH provider

Reduce license cost for spectrum → unlicensed, mmWave

- first step: LTE-U

Table 5. Wireless Network Cost Breakdown (OPEX and Headcount CAPEX)

Subcomponents	Carrier A	Carrier B	Carrier C	Carrier D	Average of All Carriers
Strategy and Support	13	8	10	19	14%
Network infrastructure rent	36	45	33	37	39%
Transmission	6	5	13	8	7%
Core Network	10	9	13	3	8%
Radio ops & maintenance	11	15	18	14	14 %
Radio deployment	13	8	8	10	10 %
Radio design	10	9	5	8	8 %

Source: Wireless Carriers Benchmarking Study

Spectrum for 5G

Changing spectrum environment

Except at highest frequencies, all new spectrum likely to be shared

- e.g., 3.5 GHz
- in time & space

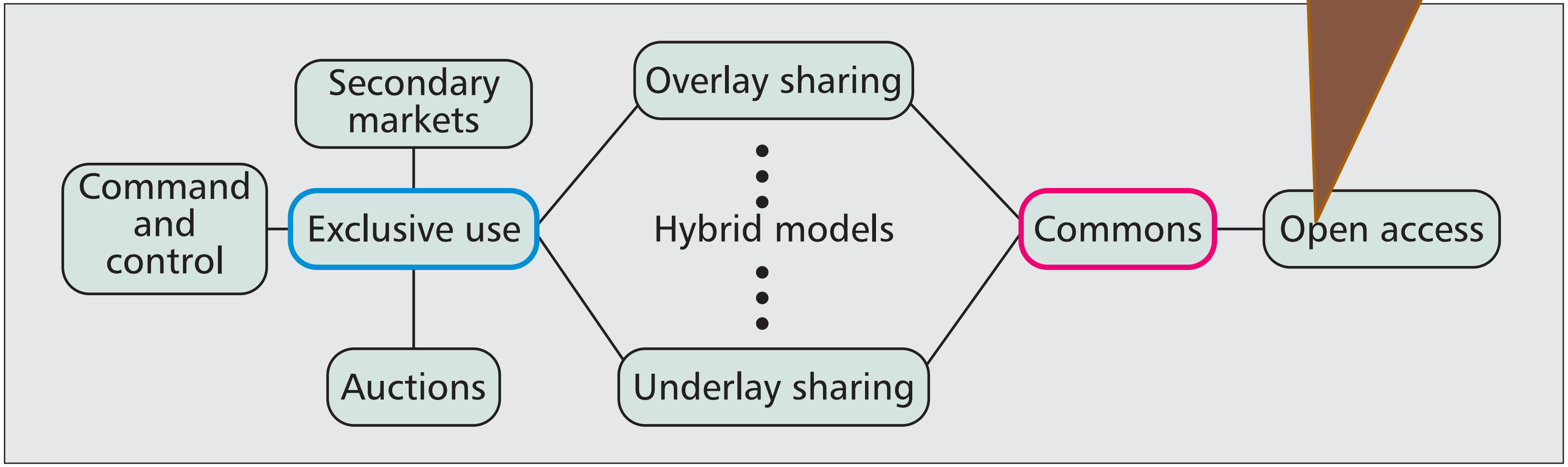
→ need frequency-agile systems that can shift capacity to different bands, quickly

→ few common bands for consulting spectrum database

- **now**: scan, pray & wait
- **5G**: shared band → database

Spectrum sharing

How much politeness & fairness is required?
→ LTE-U & LTE-LAA (license-assisted, listen-before-talk)



Ideal spectrum

Unused or cheap

Av ilable globally ( ) rtant for consum ize)

- ferably und sing conditi

No r

Propag

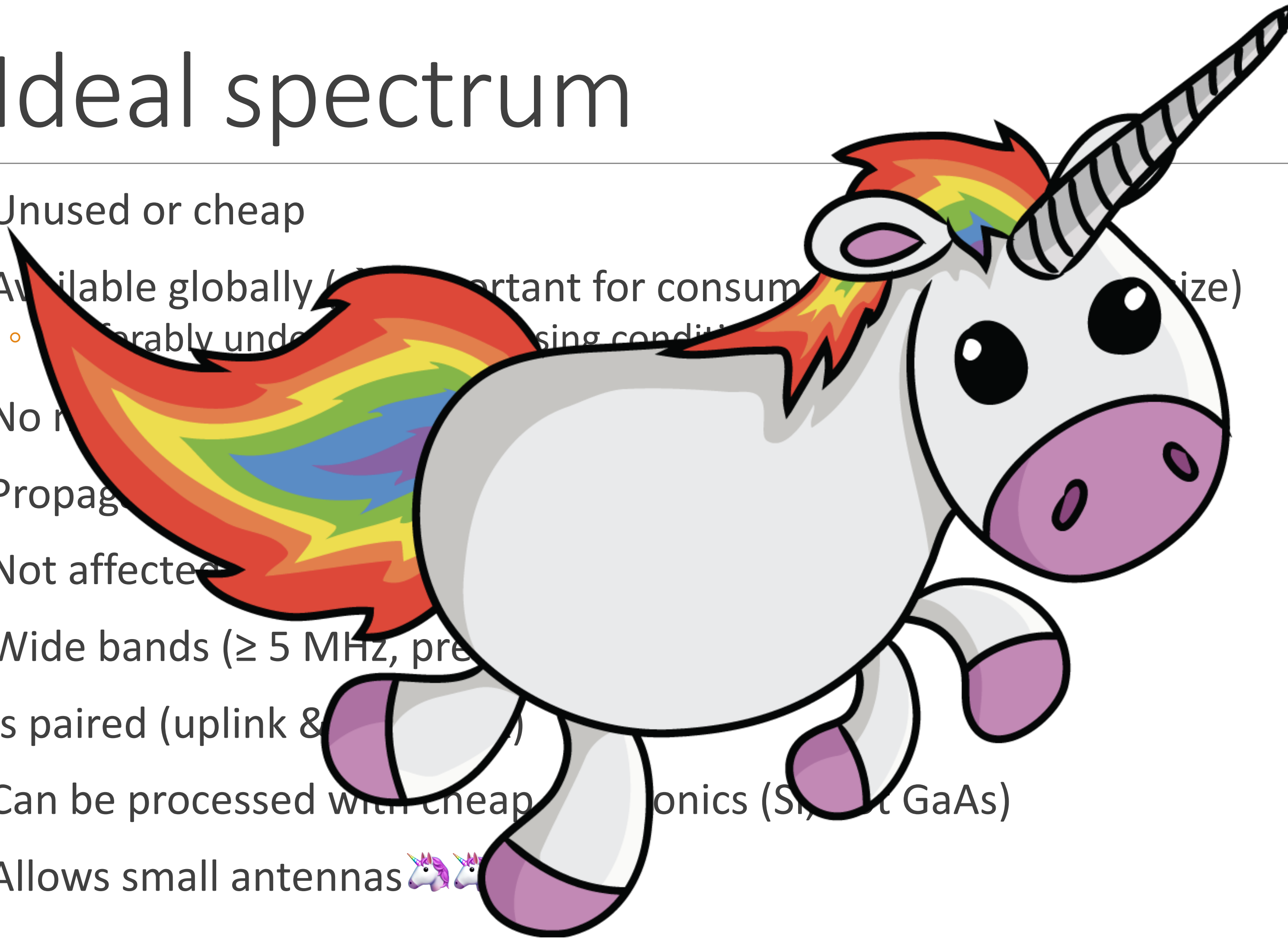
Not affecte

Wide bands (≥ 5 MHz, pre

Is paired (uplink &)

Can be processed w cheap onics (Si, t GaAs)

Allows small antennas 🦄🦄



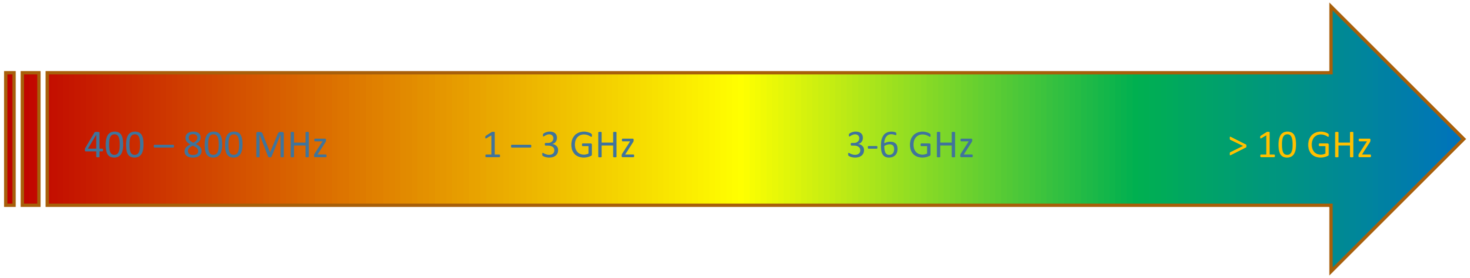
Spectrum co-existence

vs.

“high tower, high power”
(TV, cellular downlink, radar transmitter)

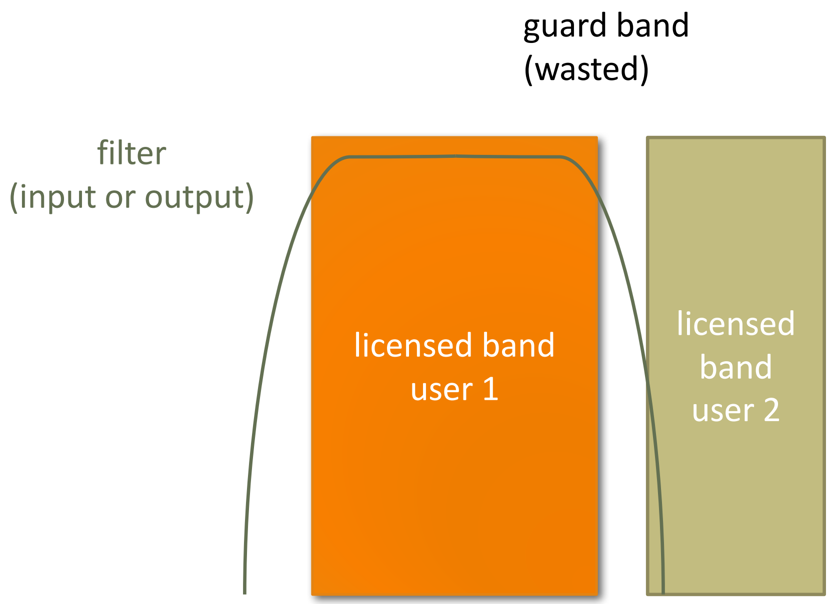
- cellular uplink
- radar receiver
- GPS receiver

Spectrum roles



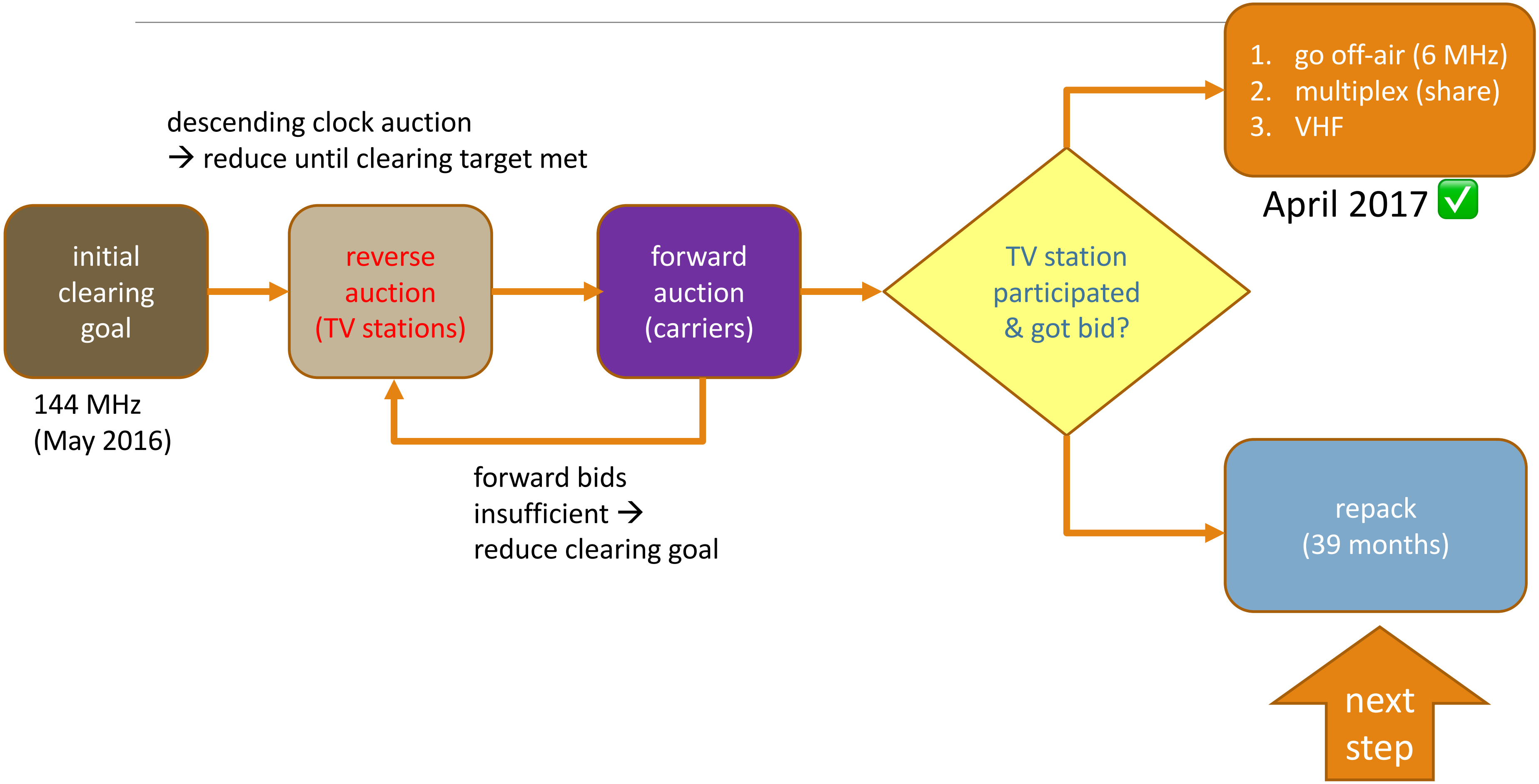
base-level coverage (particularly rural)	urban capacity	indoor & capacity	directional capacity
Digital dividend TV incentive auction	AWS-3	3.5 GHz	mmWave R&O

The filter problem

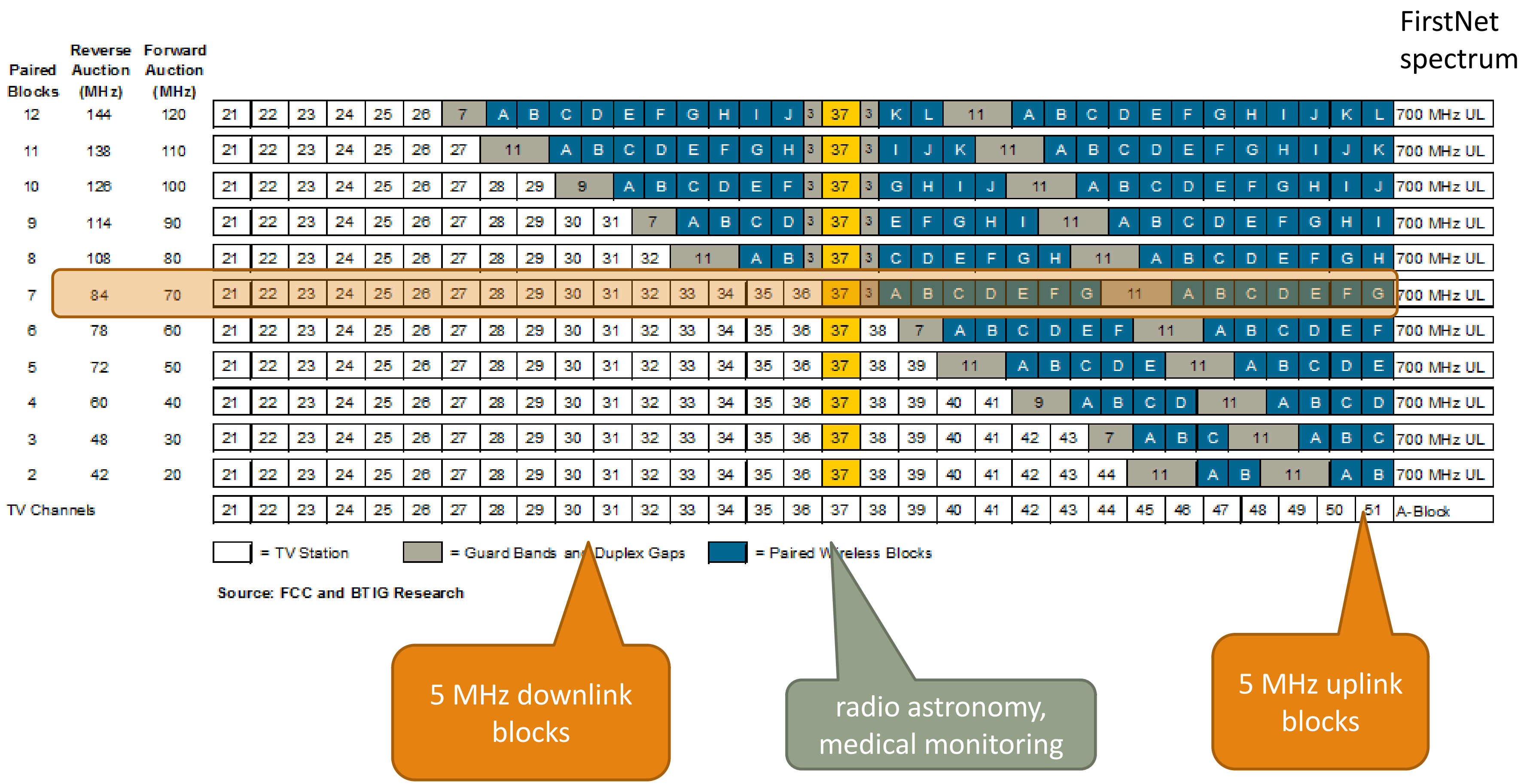


Power imbalance:
- cell downlink: 100 W ERP
- cell uplink: 0.05 – 2 W

TV incentive auction



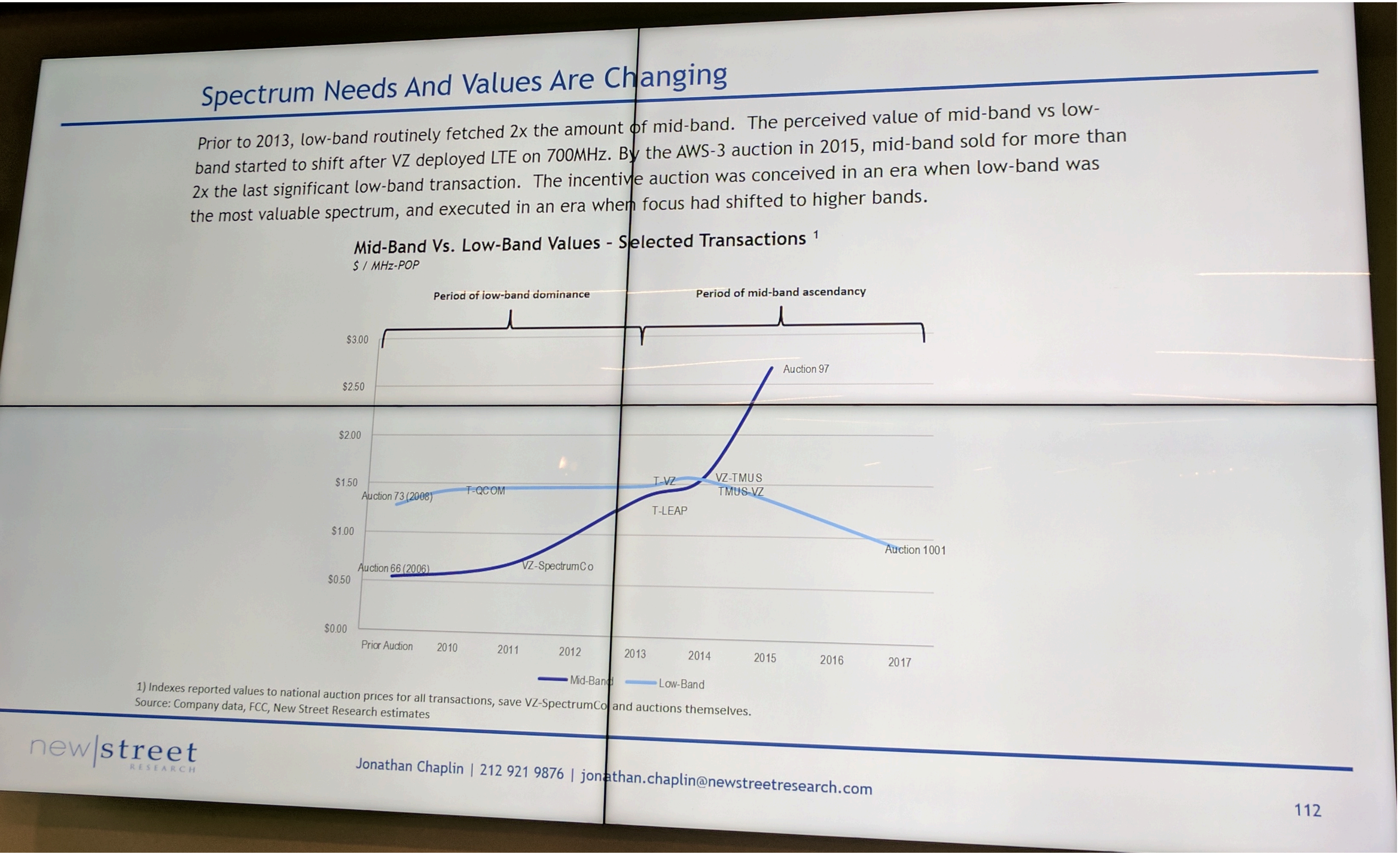
600 MHz incentive auction



Incentive auction facts

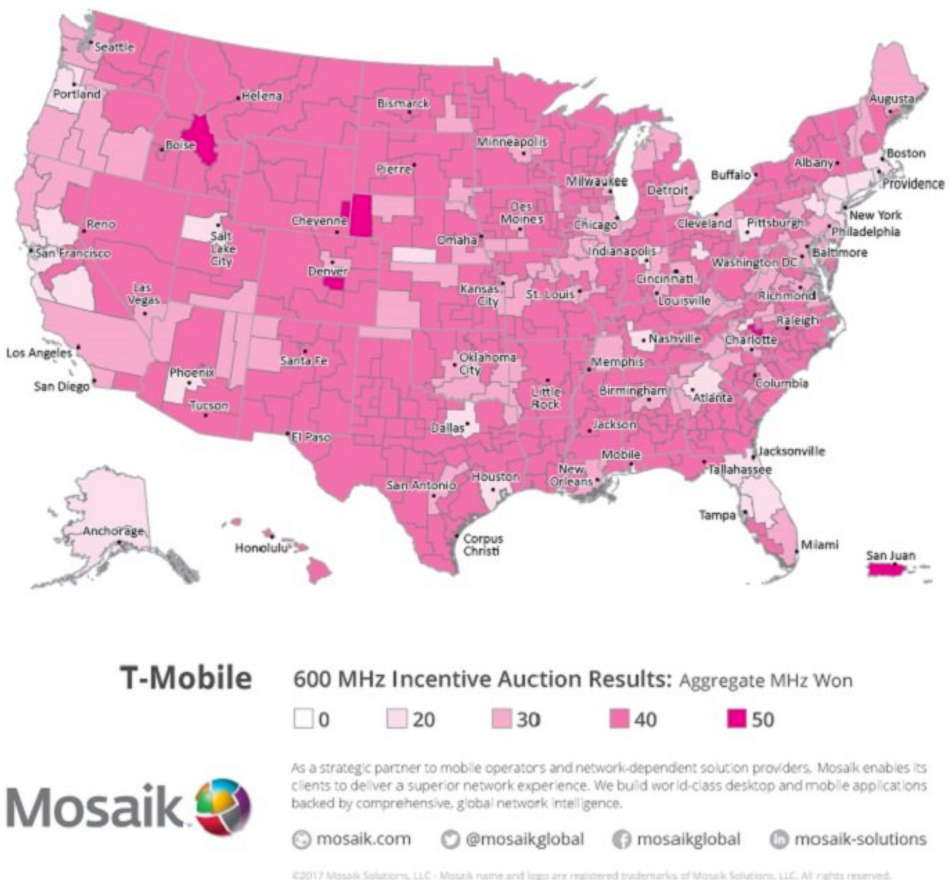
Forward Auction

$19.8 billion	Gross revenues (2nd largest in FCC auction history)
$19.3 billion	Revenues net of requested bidding credits
$7.3 billion	Auction proceeds for federal deficit reduction
70 MHz	Largest amount of licensed low-band spectrum ever made available at auction
14 MHz	Spectrum available for wireless mics and unlicensed use
2,776	License blocks sold (out of total of 2,912 offered)
$1.31	Average price/MHz-pop *sold* in Top 40 PEAs
$.93	Average price/MHz-pop *sold* nationwide



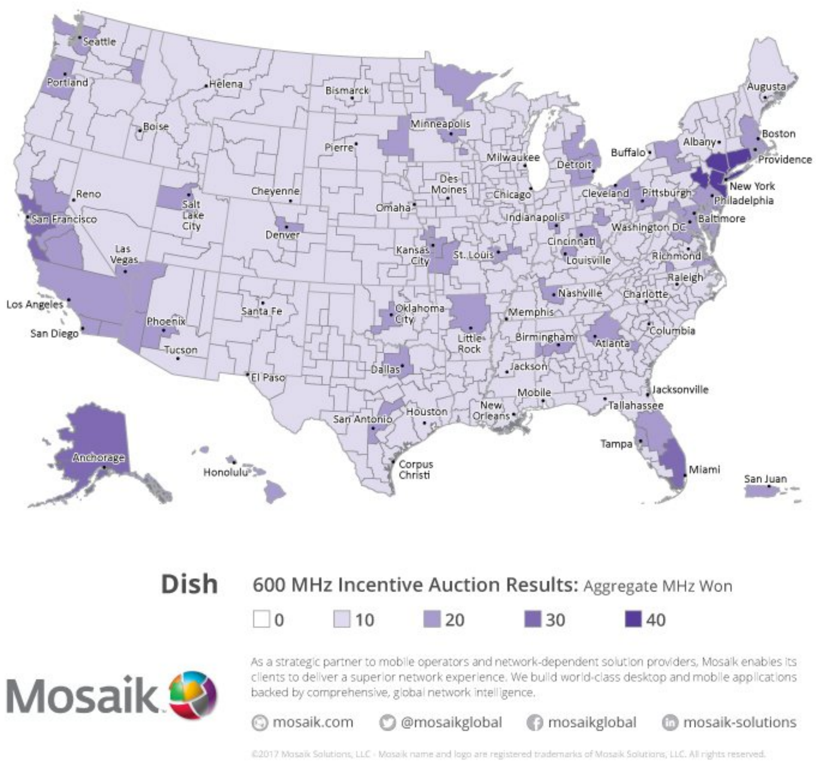
https://law.duke.edu/innovationpolicy/spectrum-incentive-auction/

Forward auction: T-Mobile



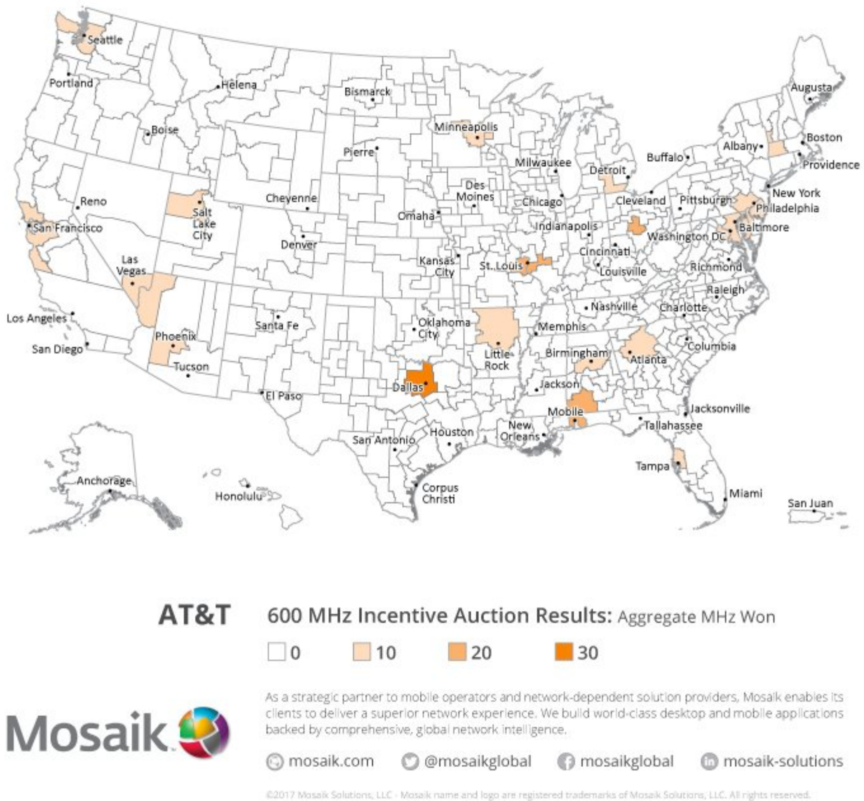
$8B

Forward auction: Dish



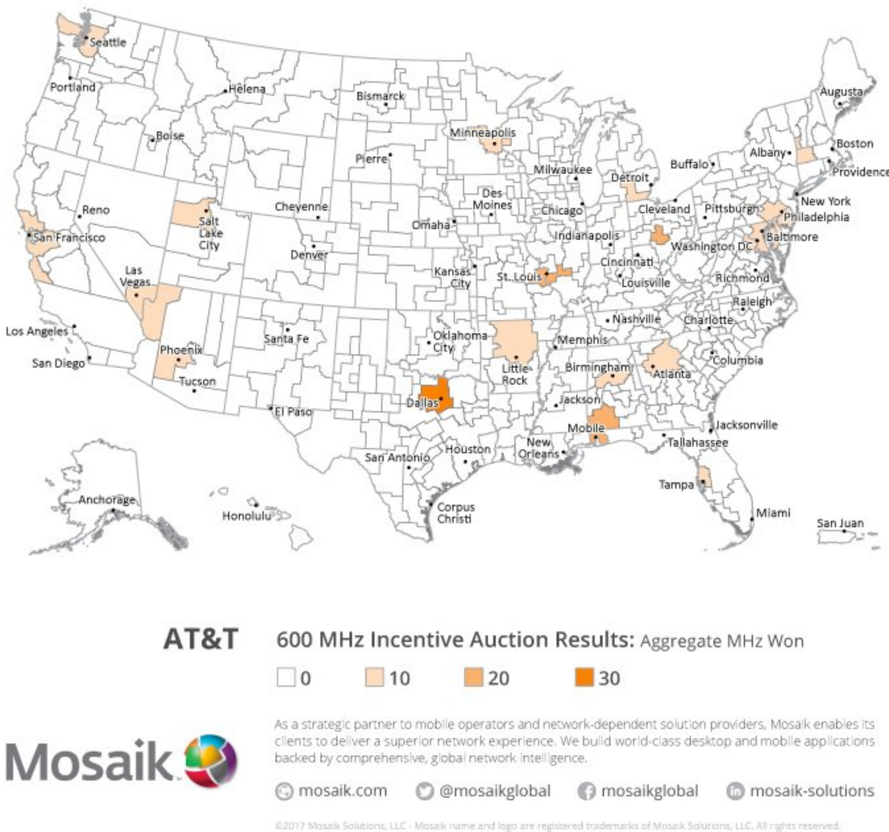
$6.2B
486 licenses

Forward auction: Comcast



$1.7B
145M POPS

Forward auction: AT&T



$1B
18 PEAs
(has 700 MHz spectrum
FirstNet spectrum

TV white spaces (US)

First large-scale spectrum database

But limited use in the US

- number of channels
- power levels
- equipment
- available mostly in rural areas, not urban
- change after incentive auction

Leonia, NJ

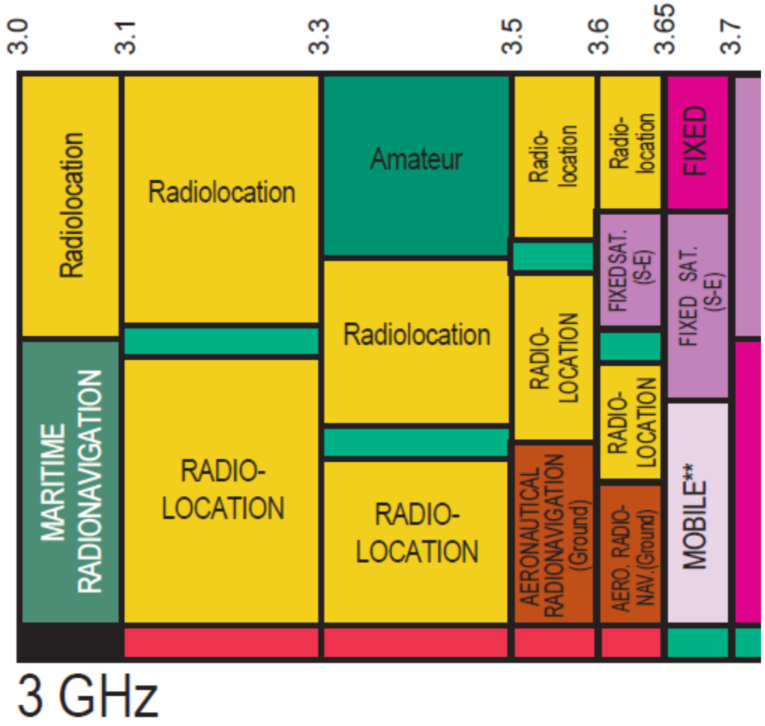
Channel Number	Frequency Range (MHz)	Allowable TX Power (mW)
42	638-644	40

Amherst, MA

Channel Number	Frequency Range (MHz)	Allowable TX Power (mW)
23	524-530	40
24	530-536	100
25	536-542	100
26	542-548	100
27	548-554	40
41	632-638	40
42	638-644	40
44	650-656	40
47	668-674	40
48	674-680	40
50	686-692	40

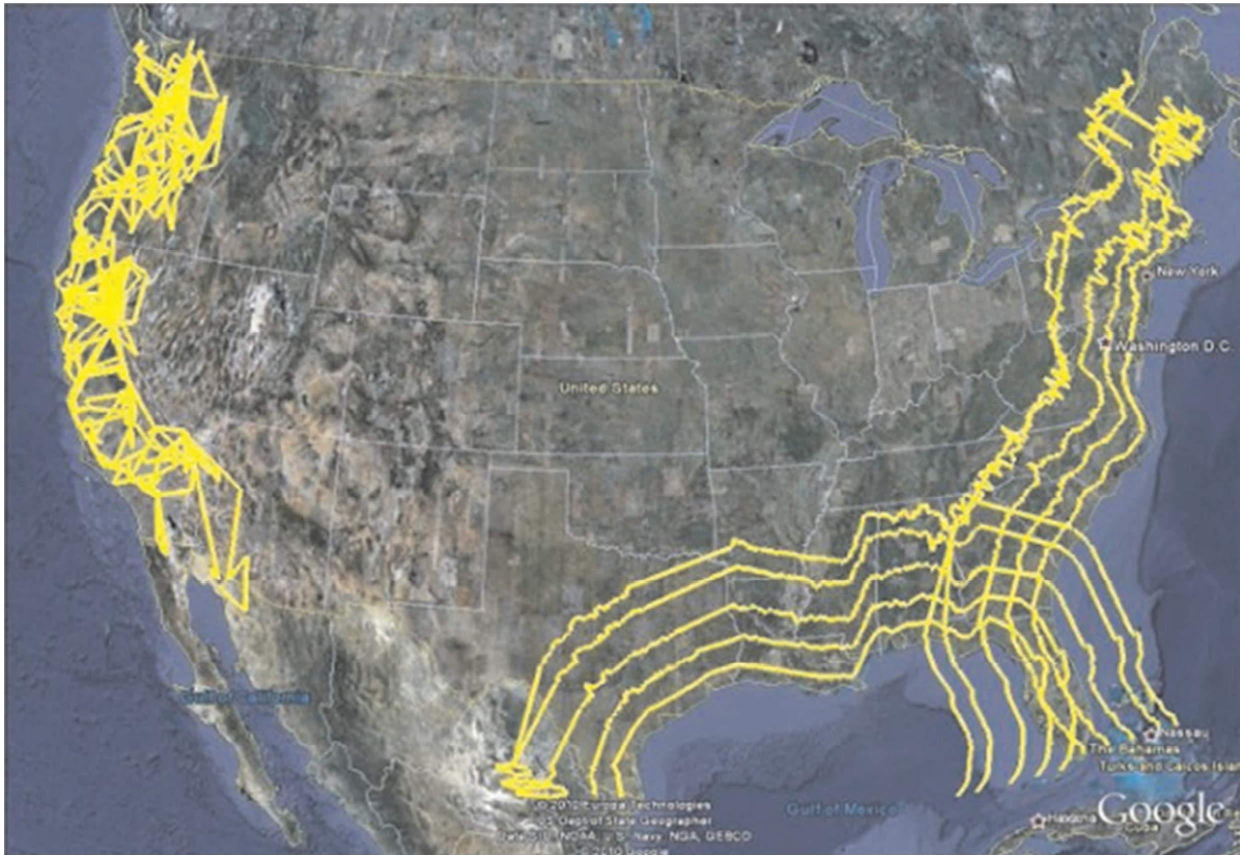
Channel Number	Frequency Range (MHz)	Allowable Antenna Height (meters AGL)
2	54-60	30
7	174-180	30
8	180-186	30
9	186-192	30
13	210-216	30
18	494-500	30
24	530-536	30
25	536-542	30
26	542-548	30

3.5 GHz band



FSS: C Band (3.625–4.200)

Federal Exclusion Zones



3.5 GHz user classes

must not interfere

1

Federal users
Fixed satellite users (FCC)

2

Priority licenses (PAL)
10 MHz channels in 3550-3650

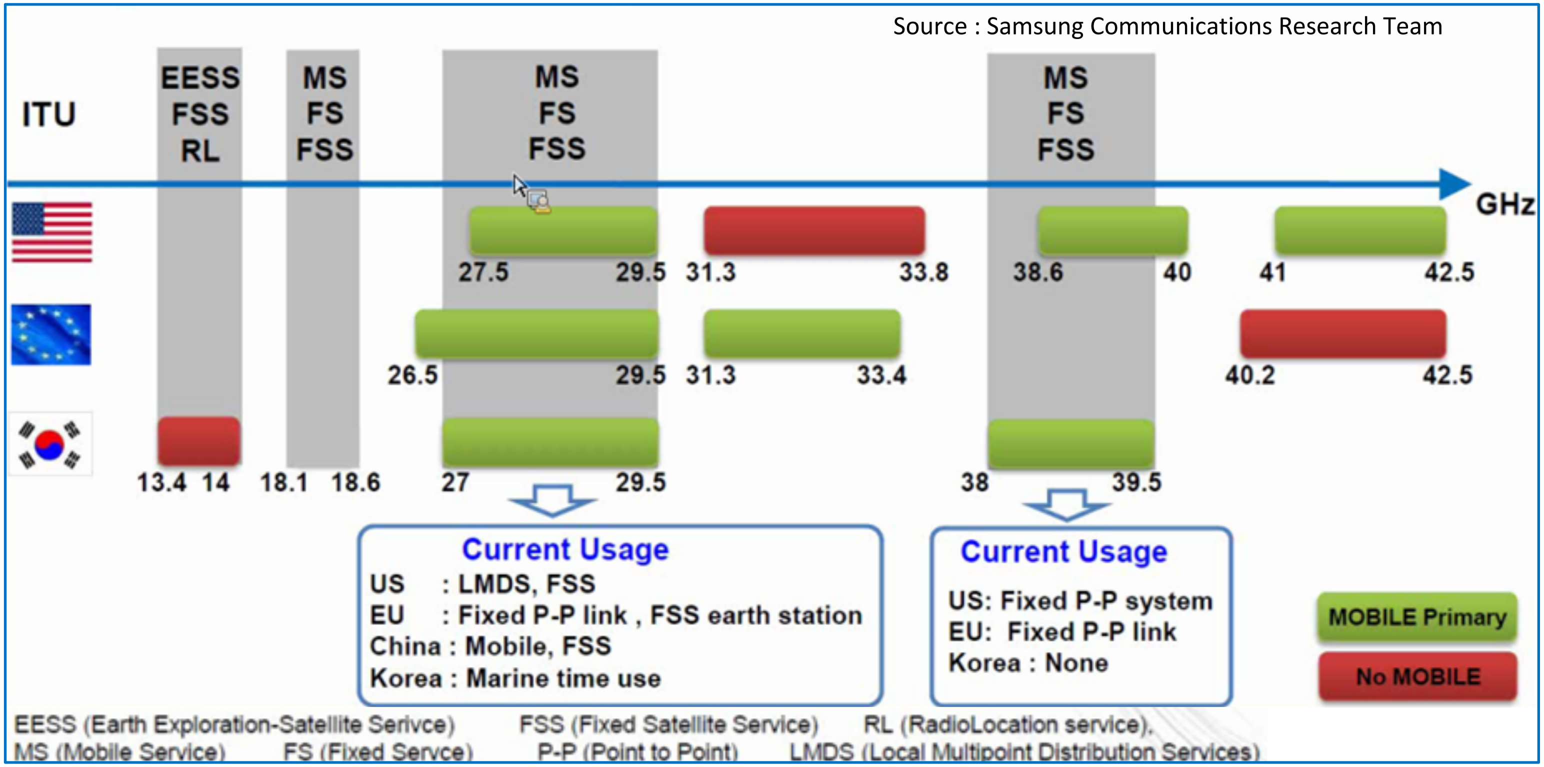
3

General authorized use (GAL)

census tract
≤ 70 MHz
3-year licenses
assigned via SAS

ESC (environmental sensing capability) allows commercial use in coastal and Great Lakes region

30-40 GHz mmW overview



- Note: The Commission’s Fixed Microwave (Part 101) and Satellite Communications (Part 25) service rules govern most of US mobile allocations shown above

MMW: Spectrum Frontiers R&O

Core Principles
- Identify substantial spectrum in MMW bands for new services
- Protect incumbent services against interference
- Flexible use: enable market to determine highest valued use
- Overlay auctions where no existing assignments
- Provide spectrum for both licensed and unlicensed use

R&O – 10.85 GHz added for mobile service (July 2016)
- Licensed bands (3.85 GHz): 27.5-28.35 GHz; 37-38.6 GHz; 38.6-40 GHz
- Unlicensed bands (7 GHz): 64-71 GHz

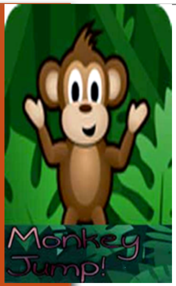
FNPRM – seeks comment on another 18 GHz & above 95 GHz
- 24.25-24.45 GHz; 24.75-25.25 GHz; 31.8-33.4 GHz; 42-42.5 GHz; 47.2-50.2 GHz; 50.4-52.6 GHz; 71-76 GHz; 81-86 GHz; bands above 95 GHz

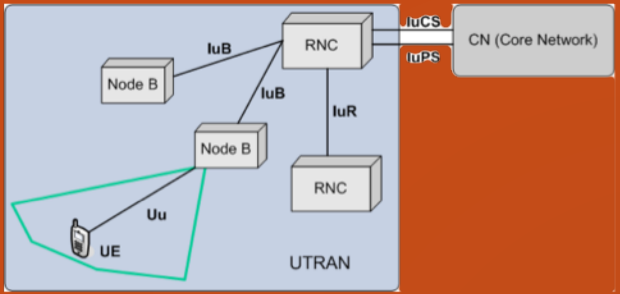
Licensing, operating and regulatory rules
- Part 30: Upper Microwave Flexible Use Service (UMFUS)
- Geographic area licensing, area size, band plan, license term

Network architecture

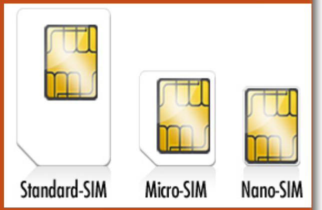
Networks 1G through 4Gish

national carrier

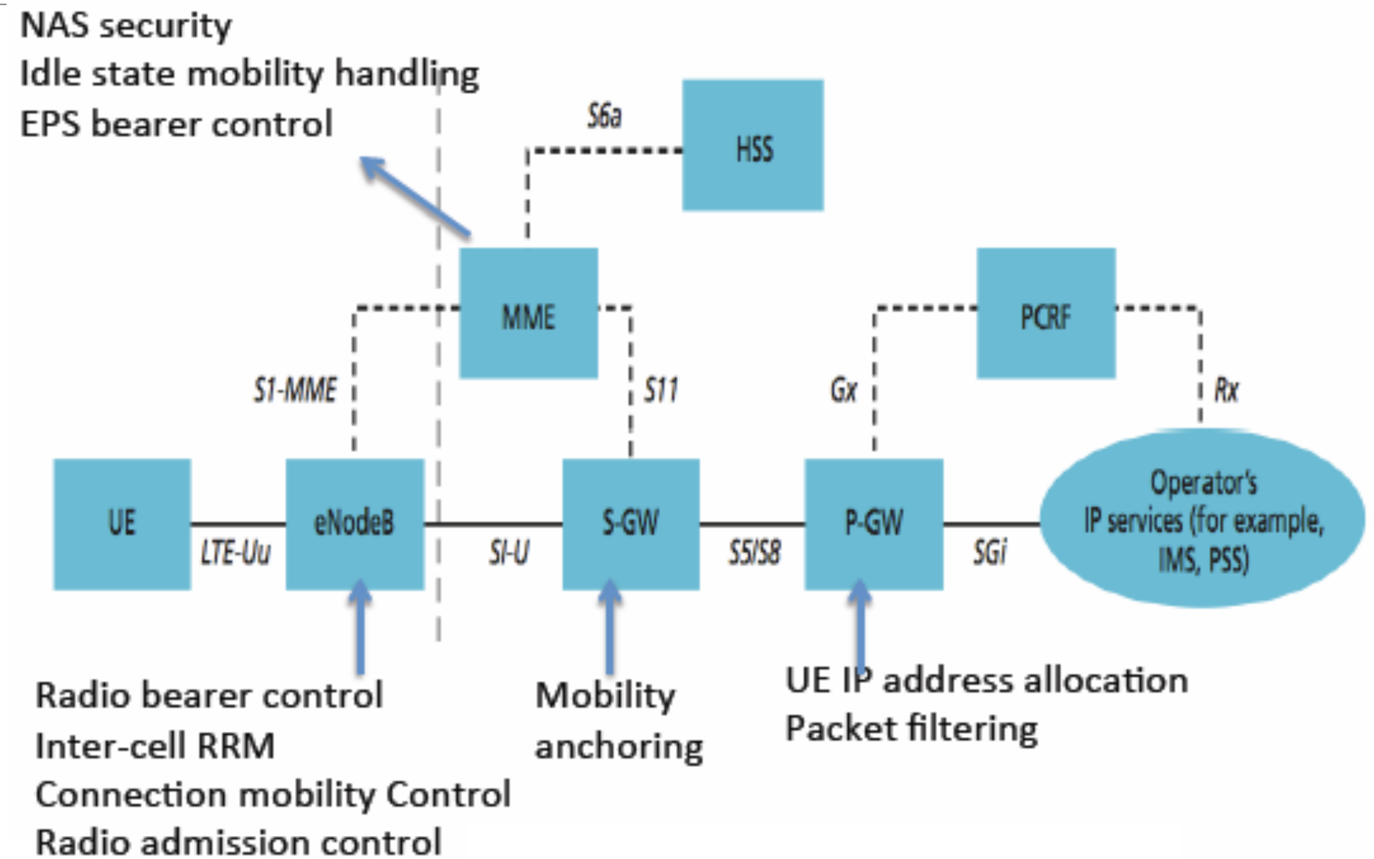




one subscriber,
one phone,
one provider



LTE – one carrier, plus roaming



5G – what exactly is a carrier?

AMERICAN TOWER®

40k towers each (US)

CROWN CASTLE

Spectrum DB

Google play

Level3
Cogent

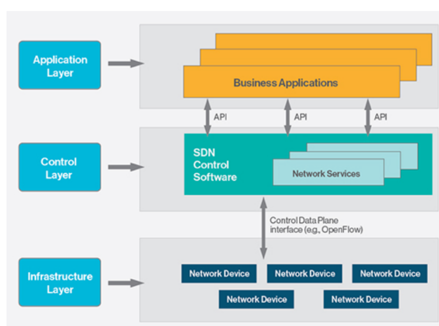
comcast

LTE-U
802.11n
LTE

FiberLight

lightower®

zayo®

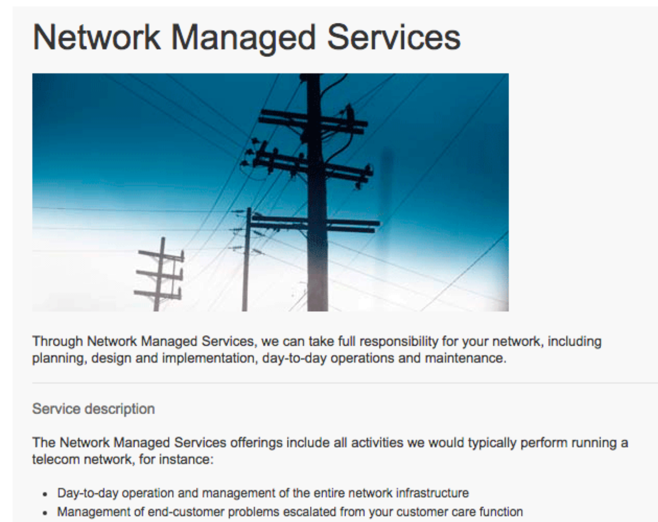


ERICSSON

5G: Carriers as consumer brand

Outside

Inside


Network Managed Services

Through Network Managed Services, we can take full responsibility for your network, including planning, design and implementation, day-to-day operations and maintenance.

Service description

The Network Managed Services offerings include all activities we would typically perform running a telecom network, for instance:

- Day-to-day operation and management of the entire network infrastructure
- Management of end-customer problems escalated from your customer care function

What are carriers good at?

Research?

Software development?

- Who is going to develop those 5G SDN applications?

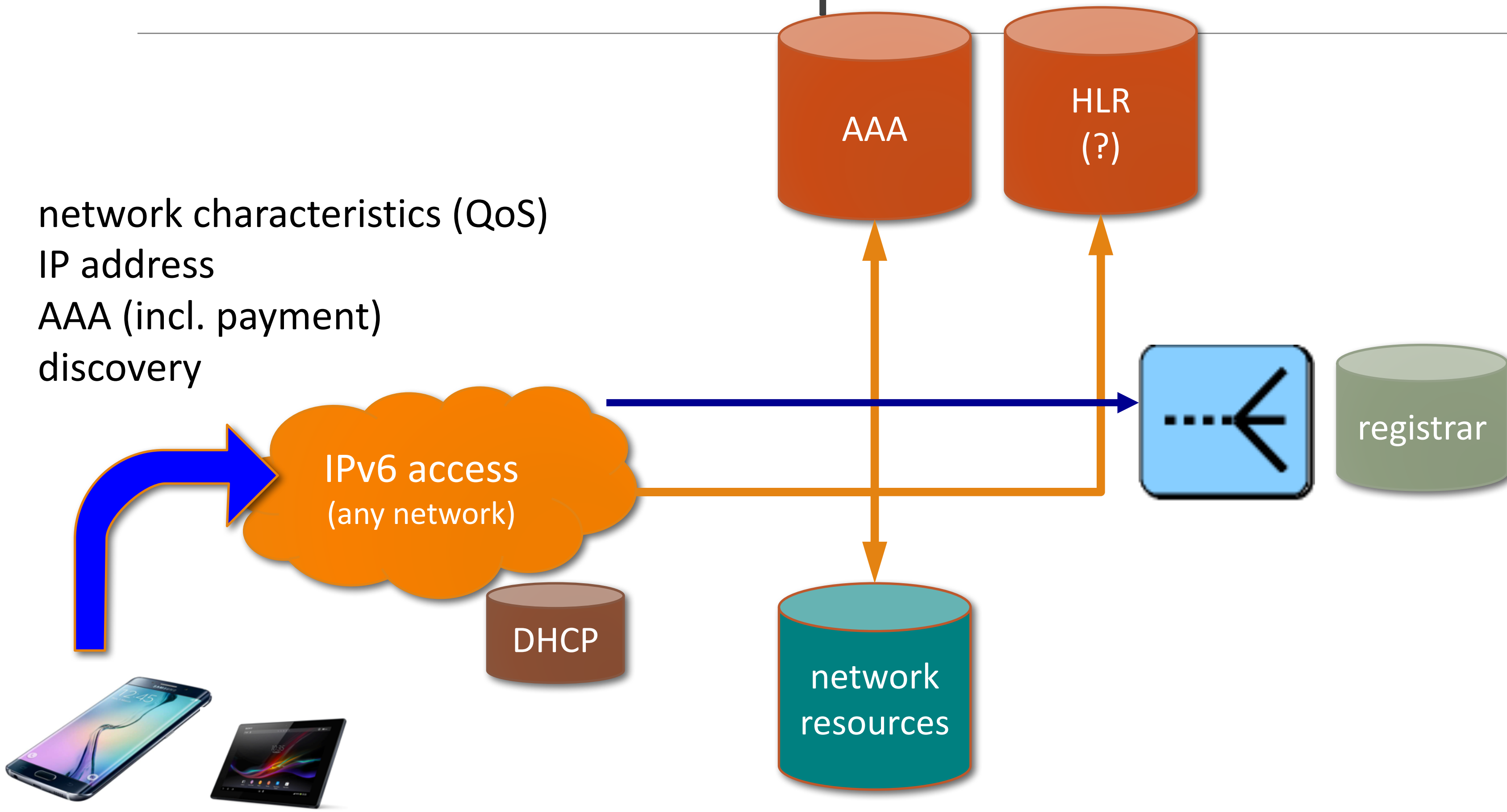
OTT applications?

API-based services?

- Why did Twilio and Tropo offer voice service APIs and not the ILECs?

What’s the simplest network?

network characteristics (QoS)
IP address
AAA (incl. payment)
discovery



one subscriber, multiple devices, multiple providers

Where do we need mobility?

likely to have access provider diversity
- what is expected lifetime of IP address?

PMIP and MIP complex
- need to re-create application-layer security at L3

not really needed for HTTP video
- use mTCP?
- or HTTP restart?

maybe not even for real-time media
- registrar for new-call reachability
- application layer (SIP) mobility for mid-call hand-off?

or tunnels, tunnels everywhere?

The law of new networks

"Any new network technology will be justified on (finally) providing QoS"

To succeed, they have to provide good-enough QoS for best effort

- at least with competition

The business model for QoS is difficult

- see bypass toll roads

QoS is usually not accessible to applications

- or not end-to-end

I-495 Express Lanes Endure Big Losses Early On Way To Potential Profit

By: Martin Di Caro
February 20, 2015

PLAY comments 2 g+1

WAMU/Martin Di Caro

The 495 Express Lanes offer a paid respite from the usual Beltway traffic, but fewer drivers than expected are using them.

The private sector firm that operates the 495 Express Lanes along the Beltway in Northern Virginia is down more than $230 million on its investment in the two and a half years since the highway opened, but company officials say toll revenues are beginning to consistently exceed operating costs, a sign the project is winning over commuters in one of the region's most congested corridors.

Transurban, the Australia-based toll road builder that operates high-speed HOT (high-occupancy toll) lanes on I-495 and I-95, has said all along it would take years to turn a profit on its enormous investments in Northern Virginia.

Providing a network API

Currently, applications can detect Wi-Fi vs. cellular

What is the correct API for discovering network properties?

- available options (“BE”, “LBE”, “low latency”)

public int **getType** () Added in API level 1

Reports the type of network to which the info in this `NetworkInfo` pertains.

Returns

one of `TYPE_MOBILE`, `TYPE_WIFI`, `TYPE_WIMAX`, `TYPE_ETHERNET`, `TYPE_BLUETOOTH`, or other types defined by `ConnectivityManager`

NetworkInfo.DetailedState	AUTHENTICATING	Network link established, performing authentication.
NetworkInfo.DetailedState	BLOCKED	Access to this network is blocked.
NetworkInfo.DetailedState	CAPTIVE_PORTAL_CHECK	Checking if network is a captive portal
NetworkInfo.DetailedState	CONNECTED	IP traffic should be available.
NetworkInfo.DetailedState	CONNECTING	Currently setting up data connection.
NetworkInfo.DetailedState	DISCONNECTED	IP traffic not available.
NetworkInfo.DetailedState	DISCONNECTING	Currently tearing down data connection.
NetworkInfo.DetailedState	FAILED	Attempt to connect failed.
NetworkInfo.DetailedState	IDLE	Ready to start data connection setup.
NetworkInfo.DetailedState	OBTAINING_IPADDR	Awaiting response from DHCP server in order to assign IP address information.
NetworkInfo.DetailedState	SCANNING	Searching for an available access point.
NetworkInfo.DetailedState	SUSPENDED	IP traffic is suspended
NetworkInfo.DetailedState	VERIFYING_POOR_LINK	Link has poor connectivity.

cost?
($ or count for bucket?)

predicted performance?

IMS /VoLTE

IMS = It Mostly Speaks
VoLTE = Voice-Only Later than Expected

VoLTE: Taking Carriers Beyond Voice

Mon, 06/06/2011 - 12:43pm

by Maisie Ramsay

Get today's wireless headlines and news - Sign up now!

Project yourself into the future – let's say mid-2012. It's been about a year and a half since Verizon Wireless first launched its LTE network in December 2010, and after a long wait, the company has finally come out with the first smartphone running voice over LTE (VoLTE) technology.

You go out and buy the device, turning it on the second you have it out of the box. One of the first things you notice: The phone's native voice application isn't limited to just voice. It has an option for video calls, and there's also an option to send multimedia messages, along with presence indicators that show when people on your contact list can participate in a video call.

AT&T, Verizon Target VoLTE Interop in 2015, RCS Later

By Doug Mohney / November 04, 2014

AT&T and Verizon have officially declared they are working on Voice over LTE (VoLTE) connections between their respective networks and customers. VoLTE calls between Verizon and AT&T customers "is expected" in 2015, according to a statement from the companies. And, there's also some Rich Communications Services (RCS) news buried in the text.

The announcement comes as three out of four major U.S. carriers promote LTE networks and a number of countries plan to turn up LTE and VoLTE in the next 15 months. "Interoperability among VoLTE service providers in the United States and around the world will create a better and richer mobile experience for customers," declares Verizon's press release.

Vodafone Germany announces VoLTE rollout

17 Mar 2015

Germany

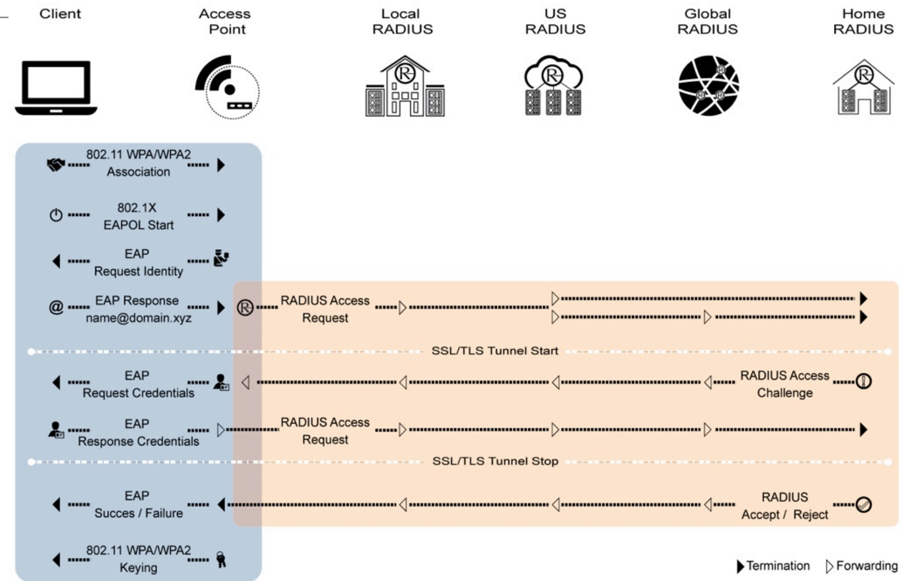
Vodafone Germany claims it has become the first German operator to initiate the rollout of voice-over-LTE (VoLTE), having demonstrated the first live VoLTE call on its network at the CeBIT 2015 technology fair in Hanover. The UK-owned operator says that the technology offers customers an 'unprecedented voice service and telephony experience', ensuring 'crystal clear voice quality, super-fast call set-up and encrypted phone calls' across its LTE network, which currently covers 70% of Germany. Vodafone revealed that it will soon be launching new LTE smartphones for VoLTE, including handsets from manufacturers such as Samsung, Sony and HTC. The announcement follows reports last week that Vodafone plans to introduce both Wi-Fi calling and VoLTE in the UK this summer, following trials of the technologies in laboratory conditions.

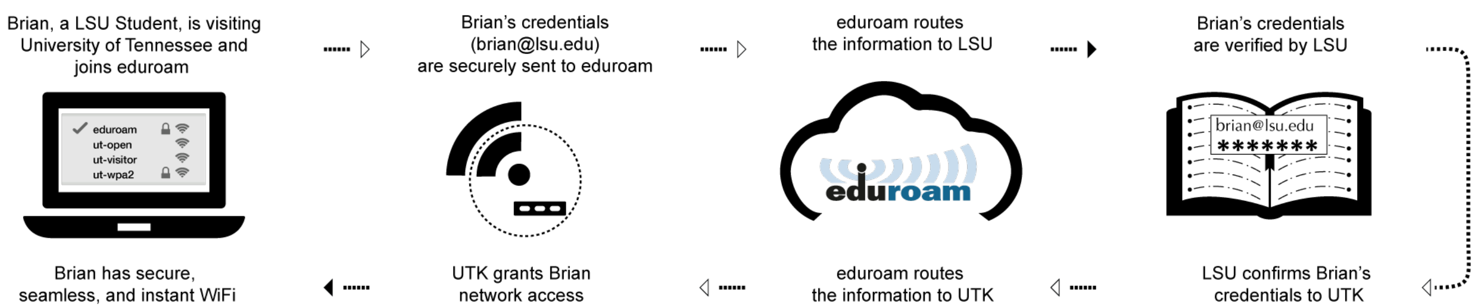
5G prototype: Eduroam

eduroam

Global WiFi Roaming For Academia

an Internet2 NET+ service





Growing-up lessons

Applications surprise

Low cost may beat QoS

Complexity kills

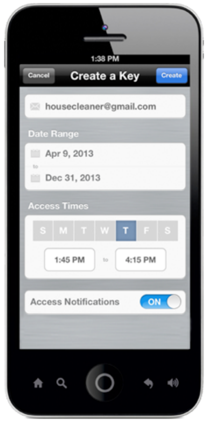
Spectrum is for sharing

5G: 4G++ or opportunity for re-thinking design assumptions

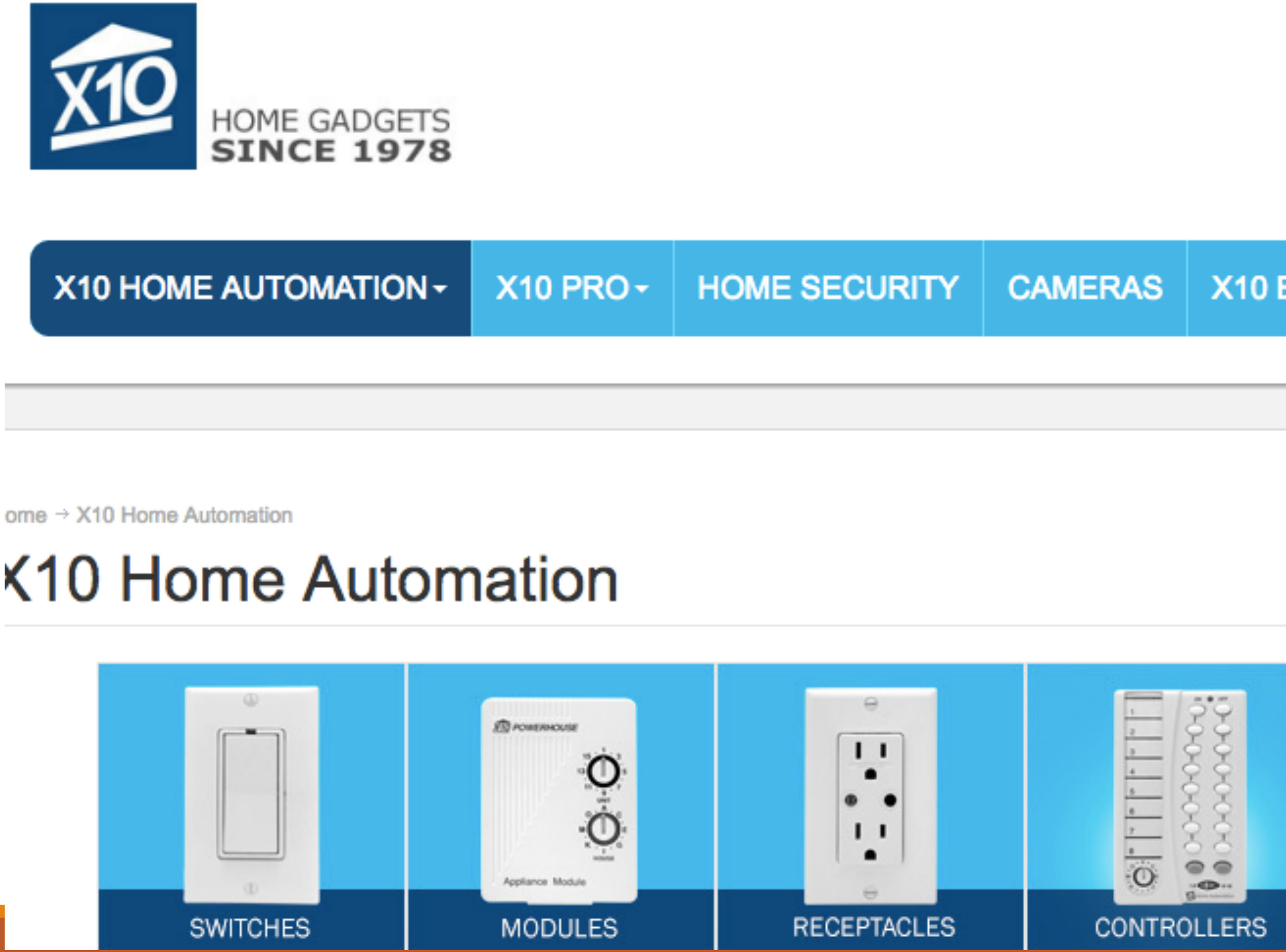
- complexity vs. modularity

IoT

Natural evolution



IoT is not exactly new (1978)



IoT – an idea older than the web (1985)

Peter Lewis (panel discussion 1985)

By connecting devices such as traffic signal control boxes, underground gas station tanks and home refrigerators to supervisory control systems, modems, auto-dialers and cellular phones, we can transmit status of these devices to cell sites, then pipe that data through the Internet and address it to people near and far that need that information. I predict that not only humans, but machines and other things will interactively communicate via the Internet. ***The Internet of Things, or IoT, is the integration of people, processes and technology with connectable devices and sensors to enable remote monitoring, status, manipulation and evaluation of trends of such devices****. When all these technologies and voluminous amounts of Things are interfaced together -- namely, devices/machines, supervisory controllers, cellular and the Internet, there is nothing we cannot connect to and communicate with. What I am calling the Internet of Things will be far reaching.*

From Chetan Sharma Consulting 2016


HUGGIES
Tweet Pee
The first diaper that tells mommy when it's time to change.
Situation
Idea
Design
Results

Towel dispensers

Power over ethernet powered paper towel dispensers

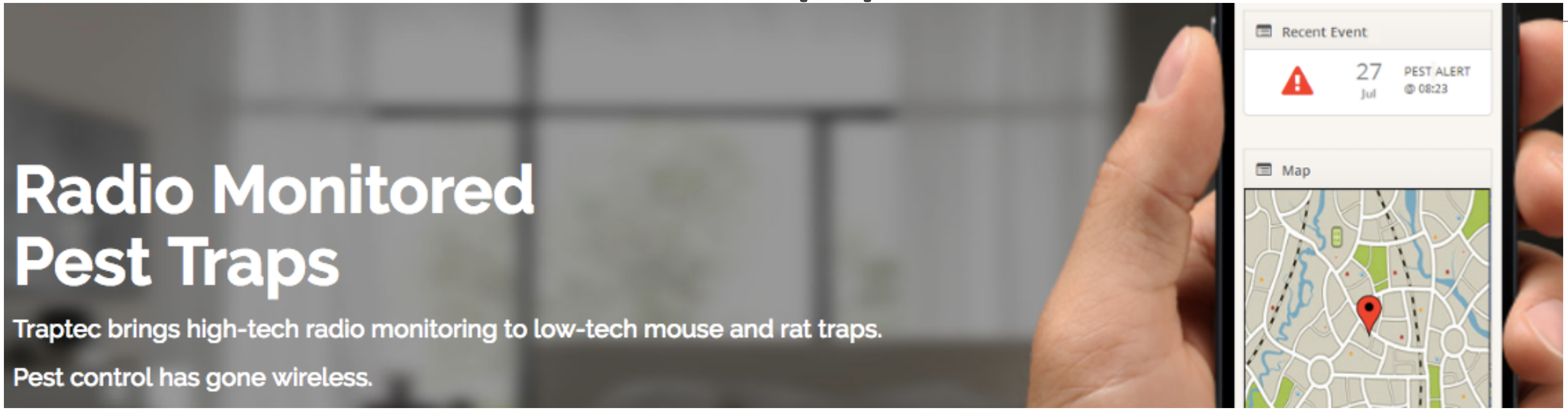
WO 2014028808 A1

ABSTRACT

A system for providing power to a plurality of paper towel dispensers (10) through a power over ethernet (PoE) network (14) and for sensing various operational parameters of the dispensers (10) and communicating those parameters through the network to a central computing device (16). The system includes a Data/Power controller (12) associated with each of the dispensers (10) for providing power (26) to the dispensers (10) and for sending and receiving data (24) between one or more sensors in the dispensers (10) and a central computer device (16).

The IoT has already been used for a range of use cases in facilities management. For example, Coor has worked with a paper towel manufacturer in Sweden to implement automated monitoring of dispensers. Sensors fitted to each dispenser monitor its fill level, and send an alert to the building manager, who can make sure it is refilled before it becomes empty.

The IoT killer app



http://www.traptec.eu/

link.nyc & smart trash cans

GPRS or CDMA
GPS location service

But controlling light switches is still not the best use

Want to turn on the bedroom light? Sure, just pick up your smartphone, enter the unlock code, hit your home screen, find the Hue app, and flick the virtual switch. Suddenly, the smart home has turned a one-push task into a five-click endeavor, leaving Philips in the amusing position of launching a new product, Tap, to effectively replicate the wall switches we always had.

https://techcrunch.com/2014/12/04/the-problem-with-the-internet-of-things/

Where does IoT make sense?

Probably

- home security
- residential & commercial locks
- home medical (recording)
- housekeeping (restroom supplies)
- outdoor lighting
- parking meters
- vending machines

Not so much

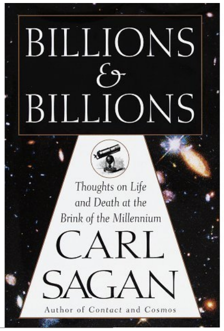
- light switches
- most household appliances
- clothing
- smoke detectors?

not cost-effective, not just useless

Two kinds of IoT devices

< $20	> $50
BlueTooth, ZigBee, proprietary L2	Wi-Fi, LTE-M, LoRa, SIGFOX
connected only via gateway	direct connection to Internet possible
fixed-function: sense or activate	SOC + network module
single chip transceiver + MPU	run (small) Linux stack
only use L2 security	programmable
similar to peripherals	TLS and kin easy

Billions & billions



Ericsson (2010): 50 billion connections in 2020

IBM (2012): 1 trillion by 2015

Gartner (2015): 6.4 billion (2016)

Stringify (2016): 30 billion (2020)

IHS Markit (2016): 30.7 billion (2020)

IDC (2016): 28.1 billion (2020)

3 billion Internet users

Uninteresting – most of these devices are just BlueTooth and Zigbee nodes talking to a gateway

About as useful as counting web pages

Sensor networks may be (tiny) niche

- Most IoT systems will be near power since they'll interact with energy-based systems (lights, motors, vehicles)
- Most IoT systems will **not** be running TinyOS (or similar)
- Protocol processing overhead is unlikely to matter
- Low message volume → cryptography overhead is unlikely to matter
  - exceptions: light switches & 1-function I/O devices → BT/Zigbee
  - Treat like USB devices

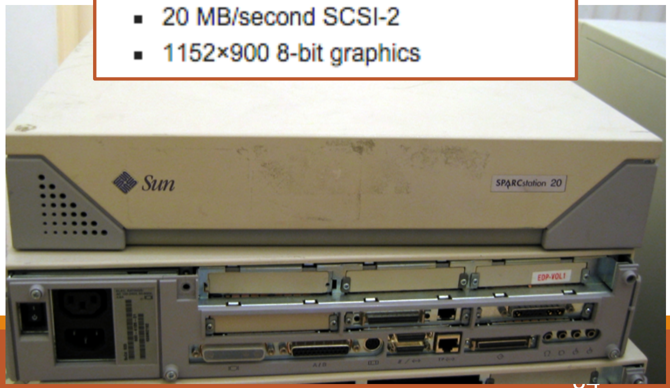
In particular, a … bout **seven** times as fast as a baseline SPARCstation 20 model 61 — and has substantially more RAM and storage, too. And the Raspberry Pi 2 is **sixteen** … l on tasks where all cores can be put to use it's **forty one times** faster.

$35.00

- A 900MHz quad-core ARM Cortex-A7
- 1 GB RAM

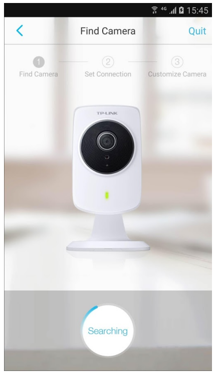
16-41x

- One 60 MHz SuperSPARC CPU
- 1 MB of cache
- 32MB RAM (expandable to 512MB)
- 20 MB/second SCSI-2
- 1152×900 8-bit graphics



http://eschatologist.net/blog/?p=266

Scaling IoT up



one device

apartment building

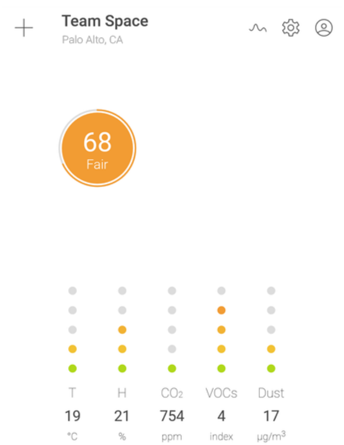
$(10^2 – 10^4)$

city+

$(10^6 – 10^8)$

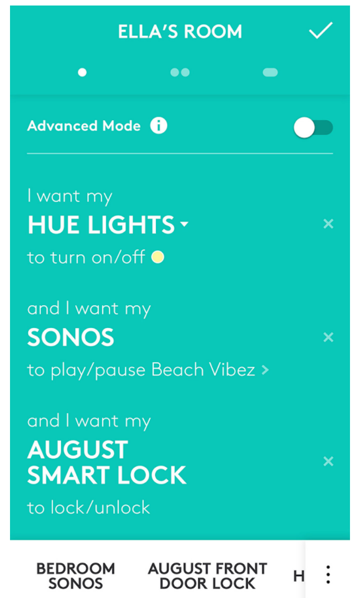
One Thing, one app

Awair



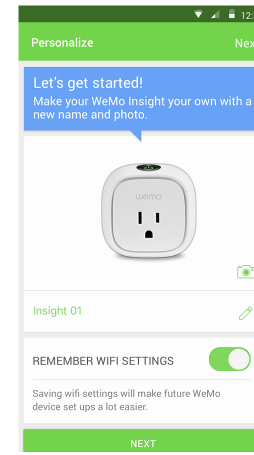
Honeywell

Logitech

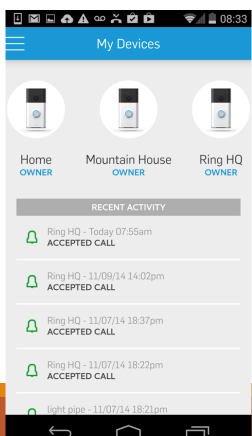


SATIS

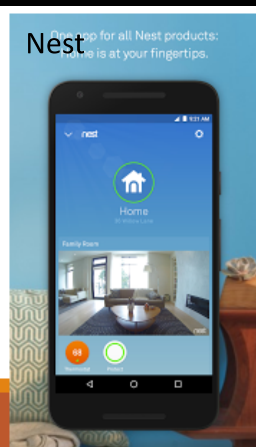
WeMo



Ring



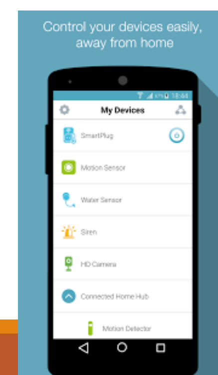
Nest



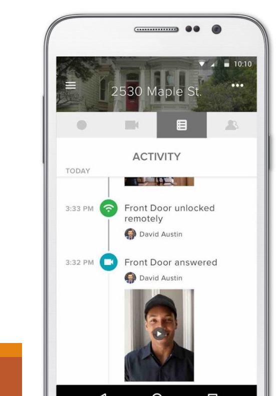
NETSYS 2017

Nespresso

D-link



August



IoT = Internet at scale

Security at scale
- still largely “add password to configuration file”
- identify by IP address

Management at scale
- device-focused
- SNMP, at best
- CLI, at worst
- no performance diagnostics capabilities (“why is this so slow?”)

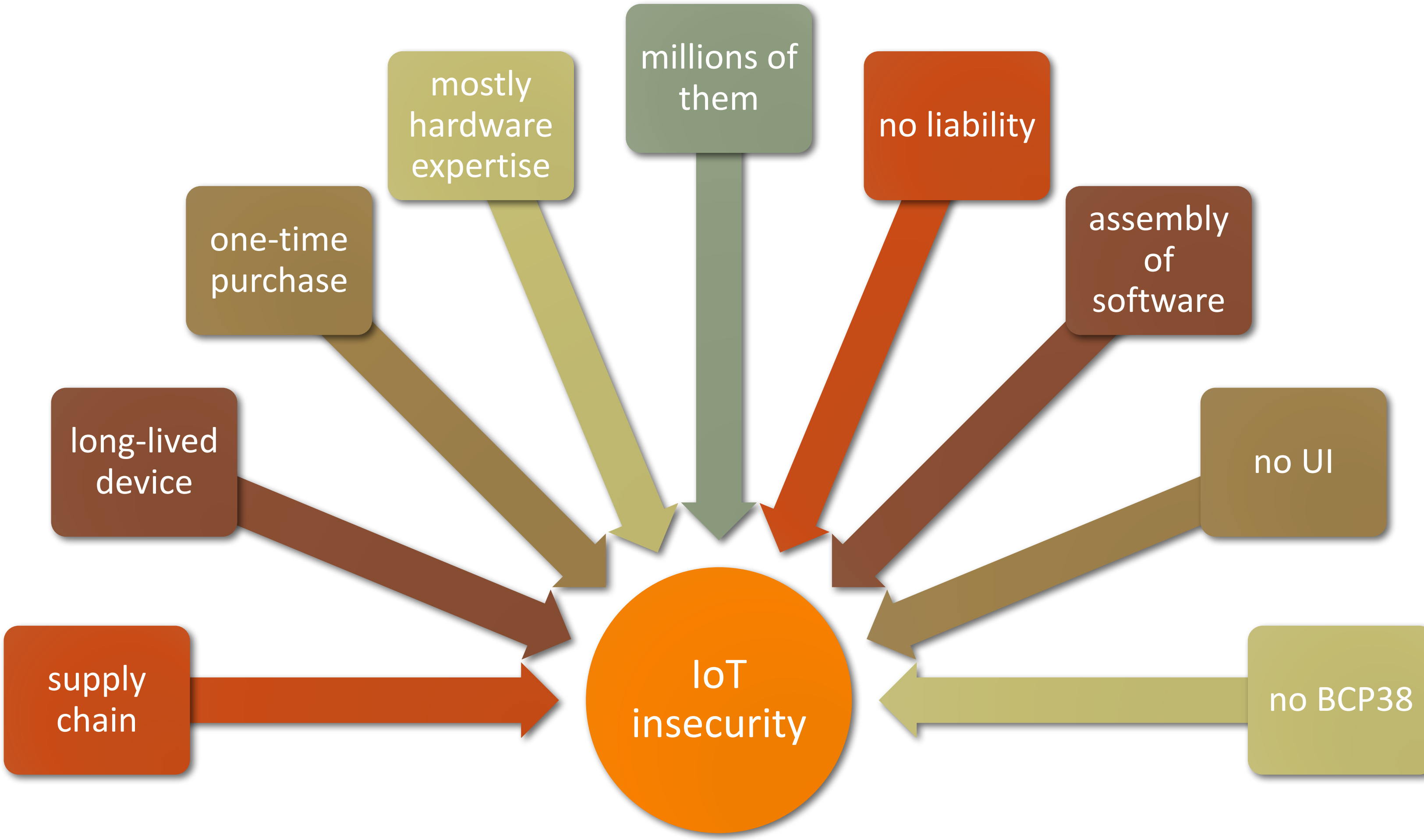
Naming at scale
- identify by node name

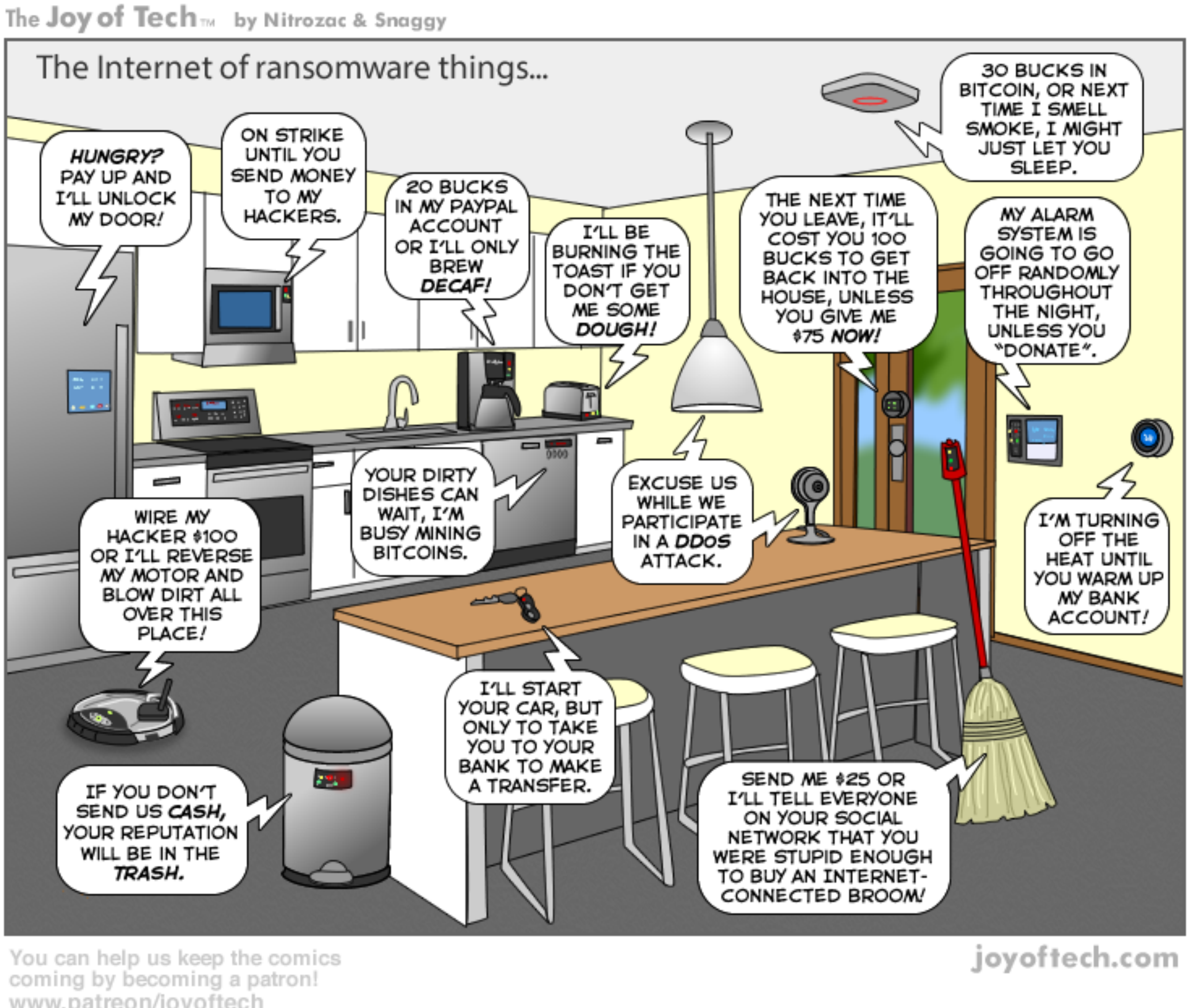
Programming at scale

system
& rack

data center

IoT security confluence




The Joy of Tech™ by Nitrozac & Snaggy
The Internet of ransomware things...
HUNGRY? PAY UP AND I'LL UNLOCK MY DOOR!
ON STRIKE UNTIL YOU SEND MONEY TO MY HACKERS.
20 BUCKS IN MY PAYPAL ACCOUNT OR I'LL ONLY BREW DECAF!
I'LL BE BURNING THE TOAST IF YOU DON'T GET ME SOME DOUGH!
THE NEXT TIME YOU LEAVE, IT'LL COST YOU 100 BUCKS TO GET BACK INTO THE HOUSE, UNLESS YOU GIVE ME $75 NOW!
30 BUCKS IN BITCOIN, OR NEXT TIME I SMELL SMOKE, I MIGHT JUST LET YOU SLEEP.
MY ALARM SYSTEM IS GOING TO GO OFF RANDOMLY THROUGHOUT THE NIGHT, UNLESS YOU "DONATE".
WIRE MY HACKER $100 OR I'LL REVERSE MY MOTOR AND BLOW DIRT ALL OVER THIS PLACE!
YOUR DIRTY DISHES CAN WAIT, I'M BUSY MINING BITCOINS.
EXCUSE US WHILE WE PARTICIPATE IN A DDoS ATTACK.
I'M TURNING OFF THE HEAT UNTIL YOU WARM UP MY BANK ACCOUNT!
I'LL START YOUR CAR, BUT ONLY TO TAKE YOU TO YOUR BANK TO MAKE A TRANSFER.
IF YOU DON'T SEND US CASH, YOUR REPUTATION WILL BE IN THE TRASH.
SEND ME $25 OR I'LL TELL EVERYONE ON YOUR SOCIAL NETWORK THAT YOU WERE STUPID ENOUGH TO BUY AN INTERNET-CONNECTED BROOM!
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Summary

Unlike 3G → 4G, 5G is mostly about capacity, not features or per-user speed

Boring is better → reduce network OpEx (and CapEx)

IoT security is exposing almost all the security deficiencies of the Internet eco system

- "thoughts and prayers" approach
- continuing to do the same thing for the next 5 years and hoping for better results is not a strategy

Start thinking beyond stove pipes of applications and home automation

→ engineering large scale systems x 10

Mobile Evolution to 5G

Business drivers and Technology enablers for 2020 networks

Dirk Wolter, Managing Director, Mobile Architecture, APAC

diwolter@cisco.com

April, 2015

Introduction: The Evolution of the Internet

Connectivity

Digitize Access to Information

- Email
- Web Browser
- Search

Networked Economy

Digitize Business Process

- E-commerce
- Digital Supply Chain
- Collaboration

Immersive Experiences

Digitize Interactions (Business & Social)

- Social
- Mobility
- Cloud
- Video

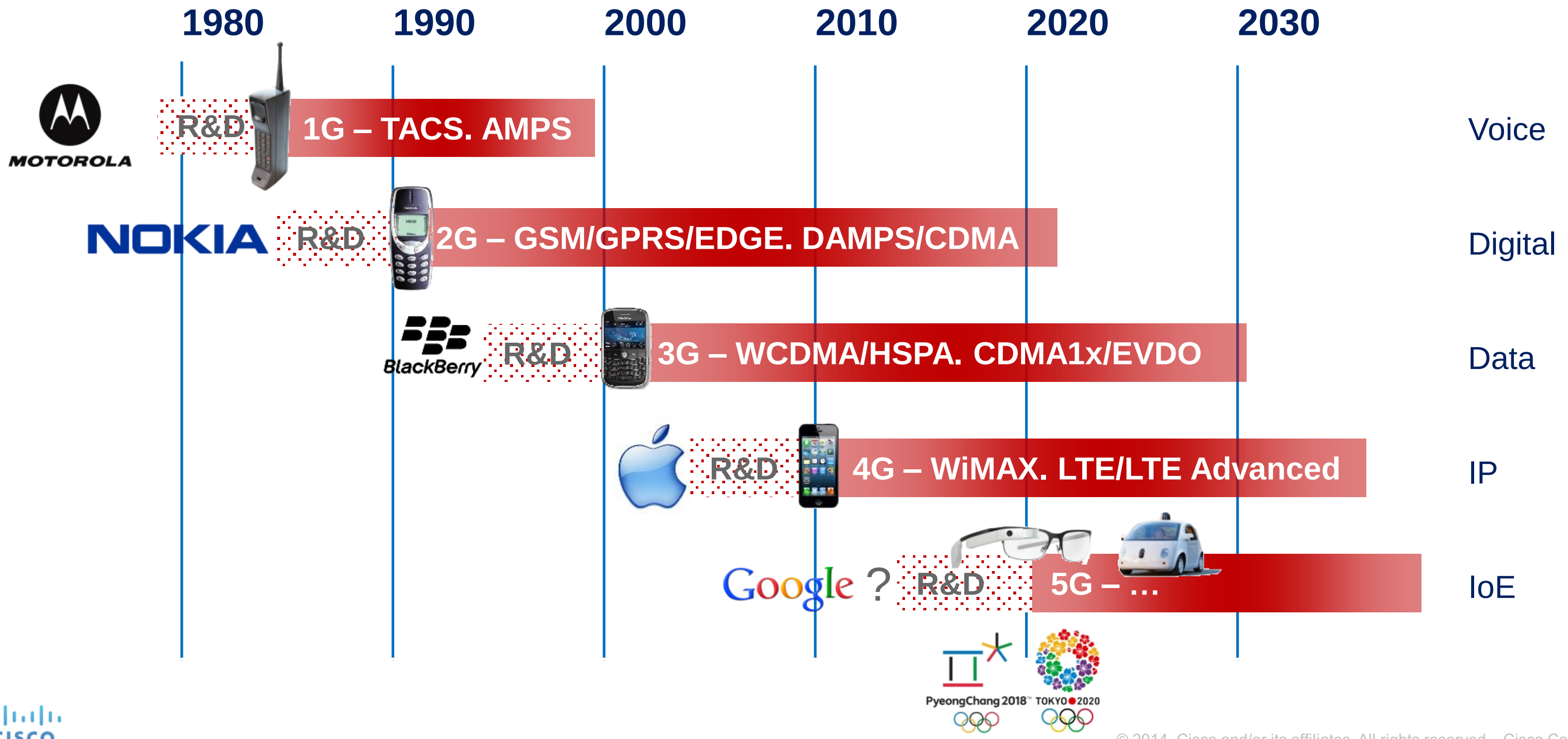
Internet of Everything

Digitize the World

Connecting:

- People
- Process
- Data
- Things

Introduction: The Evolution of Mobile Technology



Introduction: Business Transitions

New Business Models

- Flexible, usage-based pricing
- Direct, In-direct and Pass through
- IoT/IoE

New Competitors

- Global market reach over the top (OTT)
- Reduced barriers to entry
- Accelerating pace of innovation

New Financials

- Faster RoI
- Predictable OpEx
- Start-up innovation
- Agile Dev-ops

Strategic Options: 1. Smart Utility 2. Platform provider/enabler 3. Diversified player

5G 2020 Vision

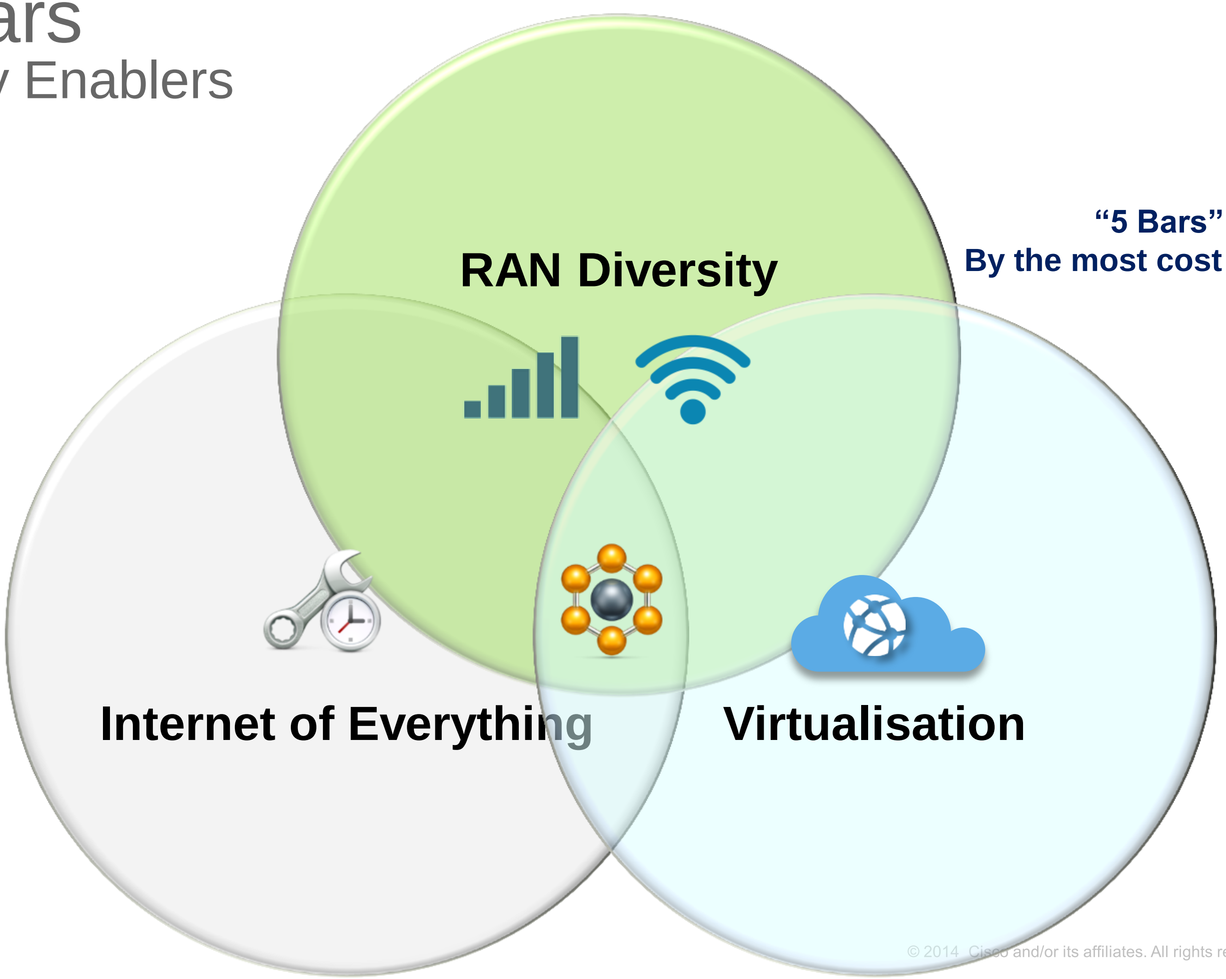
- Services
  - Ubiquitous bandwidth (no more cell edge)
  - HD video everywhere (up and down)
  - Internet of Everything (M2M, M2P & P2P)
  - Sensing, Presence and Ad-hoc networking
  - Web eco-system of Apps and Services

- Technical Requirements

1. Higher System Capacity	1000x capacity/km2
2. High Data Rates	10-100x current 4G rates
3. Lower Latency	Below 1ms
4. Mass Connectivity	100x connected devices
5. Energy Efficient	10x Network and Device power savings
6. More Agile	10x faster time-to-market

5G: Pillars
Technology Enablers

“5 Bars” Service
By the most cost effective access



Provide Business Solutions

Lower TCO
Increase Agility

Internet of Everything Service Providers

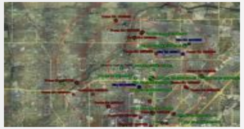
Connections / Impacts

M2M

Connections

- Cars/Trucks
- Roads
- Appliances sensors
- Digital billboards
- Vending
- Inventory (RFID)
- Office facilities

Impacts



Remote Site Monitoring Service

M2M Commerce

Intelligent Diagnostics

Targeted Advertising

M2P

Connections

- Intelligent GPS
- Home security devices
- Home energy devices
- Automated customer notifications
- Auto-translation
- Sponsored data
- Connected Life

Impacts

Personalized Traffic report

Hyper Location Presence

mHealth Order Refills

Home Security Energy Control

P2P

Connections

- Video cameras
- Television
- Digital signage
- Social media
- Contact center

Impacts

Collaboration as a Service

TelePresence as a Service

Smart Health

5G Enables the Internet of Everything

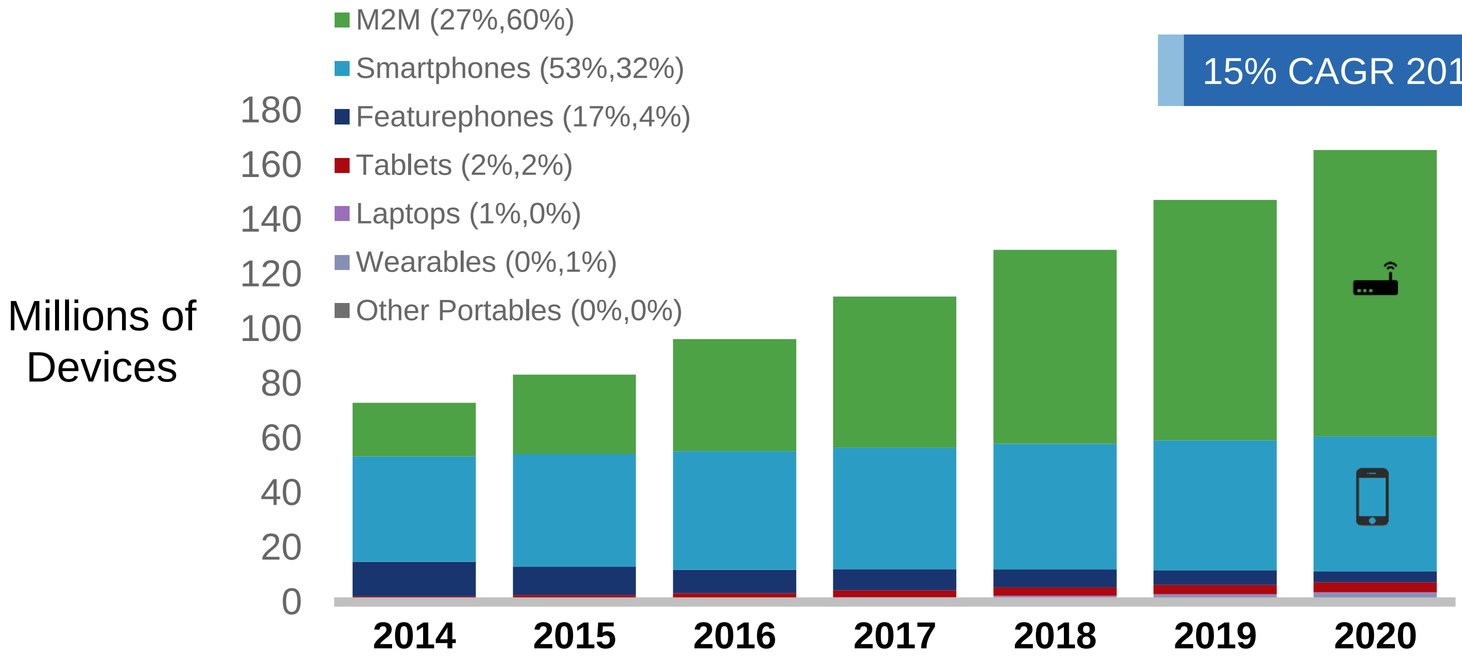
	2003	2010	2015	2020
World Population (Billion)	6.3	6.8	7.2	7.6
Connected Devices (Billion)	0.5	12.5	25	50
Connected Devices per Person	0.1	1.8	3.5	6.6

More Devices than People

3G → 4G → 5G

Korea: Mobile Device Growth by Type

Smartphones already dominate share, M2M is growth driver



15% CAGR 2014–2019

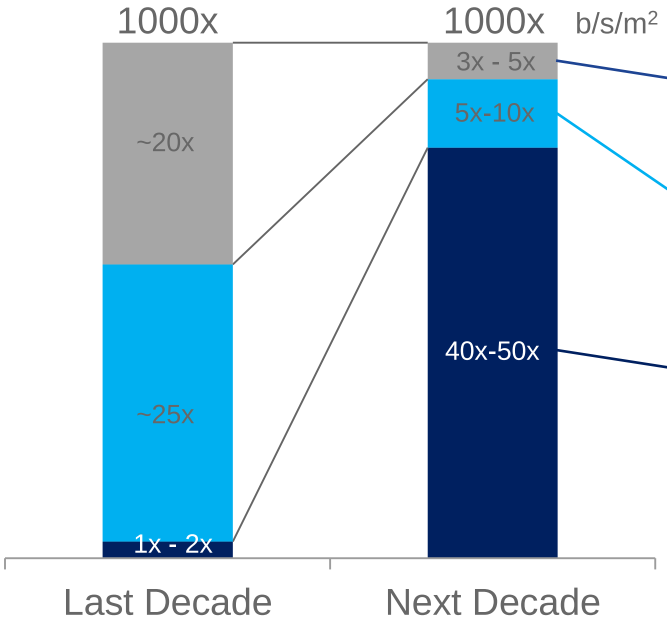
2020:
- 165M Devices
- 230M Connections
- 46M Users

*** Figures (n) refer to 2014, 2019 device share**

Source: Cisco VNI Global Mobile Data Traffic Forecast, 2014–2019

5G: Role of HetNet

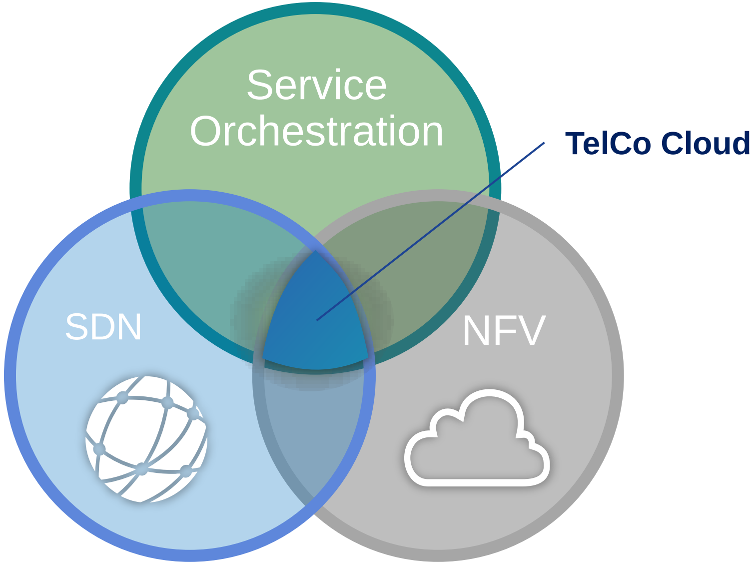
Trends of Network Capacity Growth



Air Interface	• Coordinated Multipoint Tx/Rx • 3-D/Full-Dimensional MIMO • New Modulation and/or Coding Schemes
Spectrum	• More Licensed and Unlicensed Spectrum, Millimetre-Wave Bands • Licensed Shared Access • Unlicensed Spectrum Sharing
Network Devices	• Cell Densification • Wireless Local Area Networks (WLAN) Offloading • Integrated Multiple Radio Access Technology (RAT) Operation • Device-to-Device • Joint Scheduling • Information & Communication Technology Coupling

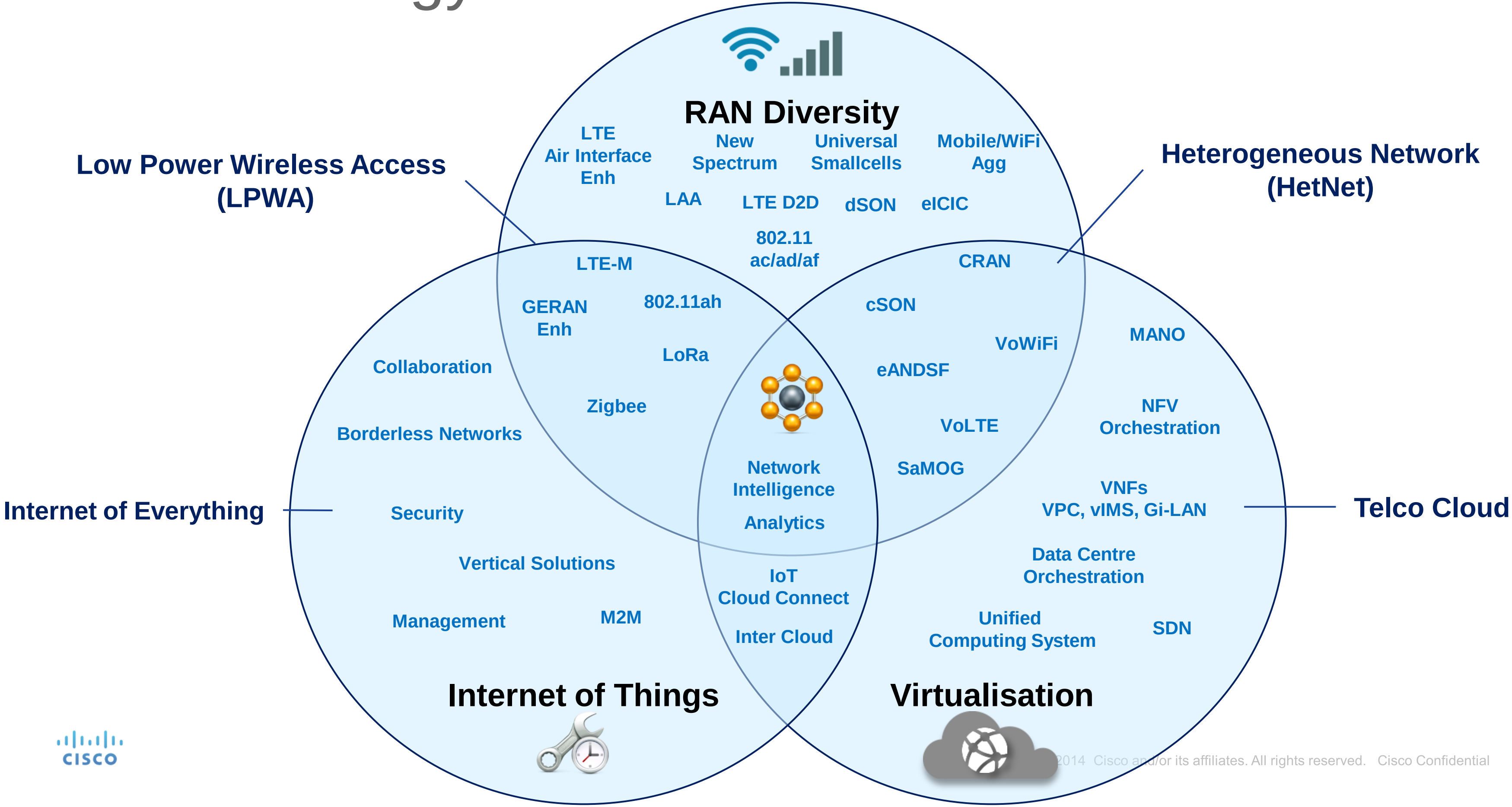
Source: 5G Network Capacity, Key Elements and Technologies, Qian (Clara) Li, Huaning Niu, Apostolos (Tolis) Papathanassiou, and Geng Wu, Jan 2014

5G: The role of SDN and NFV

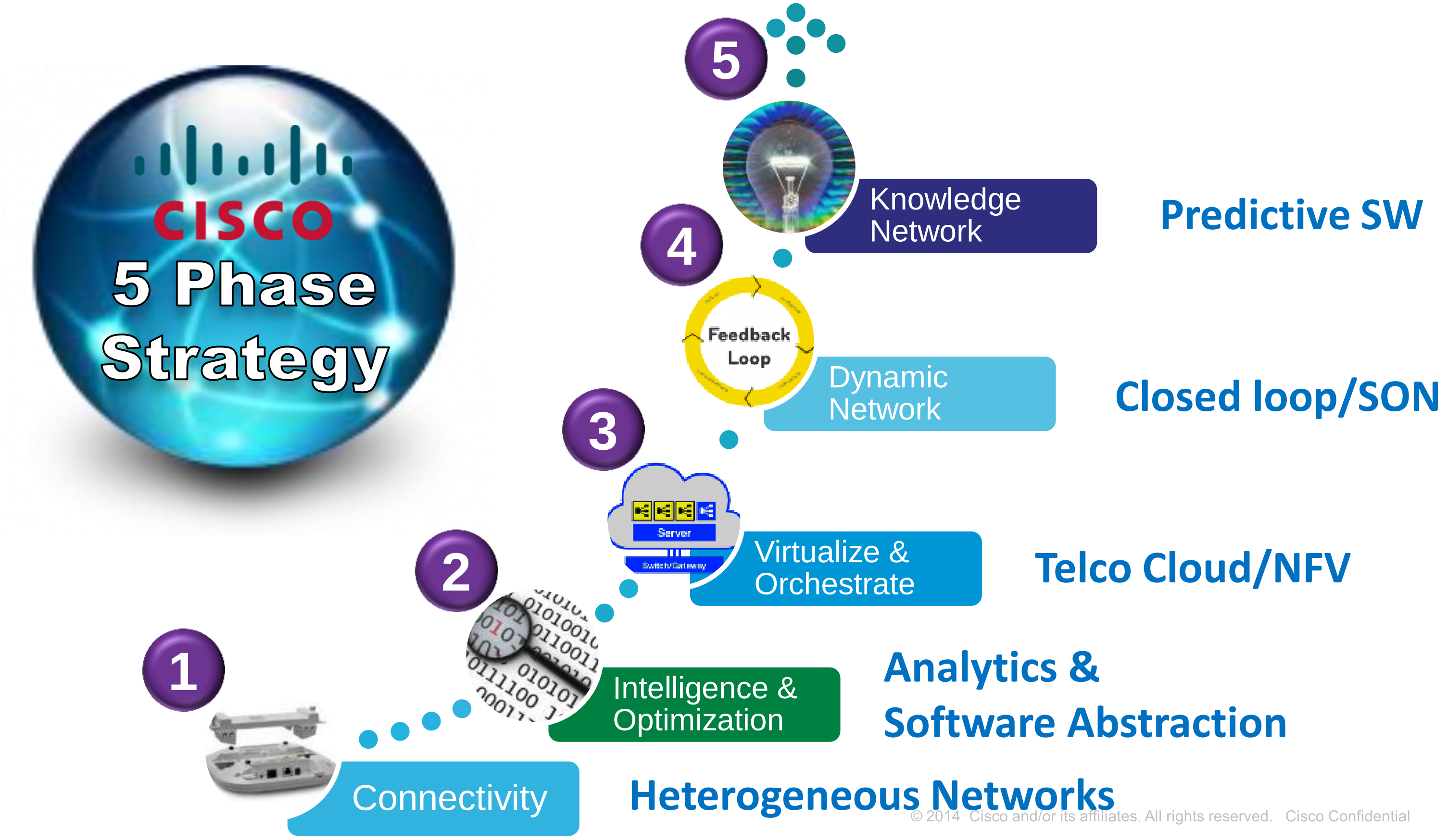


- 5G TCO and flexibility demands **Orchestrated** software-based virtualised network resources.
- Optimised virtual network functions (**NFV**) tailored to each application requirements, e.g.
  - M2M Telemetry
  - M2M Video
  - Mobile Internet
  - Enterprise Cloud Services
  - Public Safety, etc.
- Each configured dynamically (**SDN**) using transport & compute resources from the same or different sources based on cost & availability.
  - Centralised and/or distributed
  - Private and/or Public Cloud

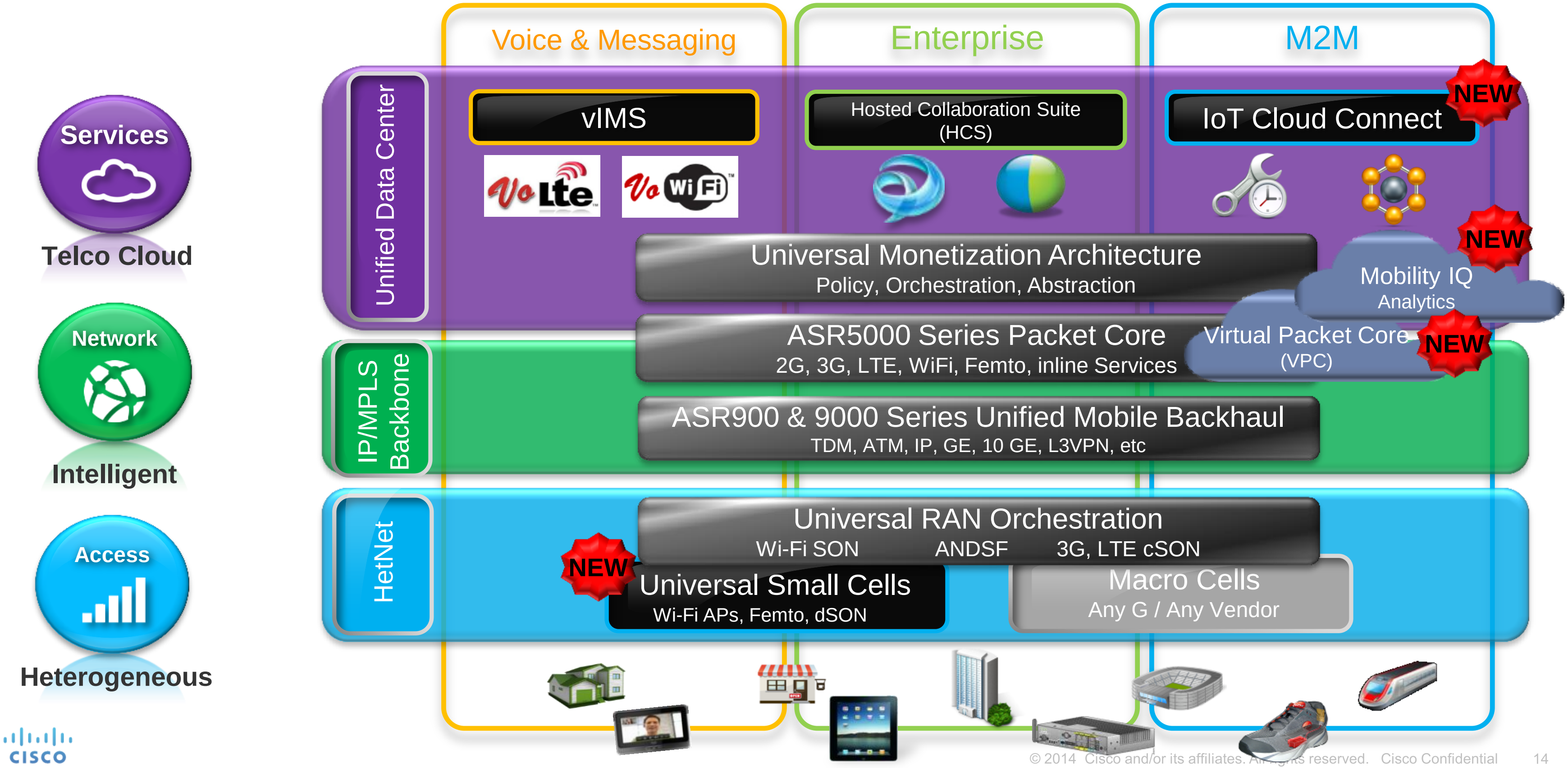
5G: Technology Enablers from Various Sources



Mobile Network Evolution 5 Phase Strategy



Cisco Mobile Internet Architecture



Summary

- 5G is about Evolution not Revolution to a 2020 world
- Mobile first, Video by default, Internet of Everything, Web Apps & Services
- 5G networks will be built on 3 themes:
    1. Internet of Everything Enablers
    2. RAN Diversity
    3. Virtualistion
- Cisco Mobile strategy builds on these to transform 4G networks of today

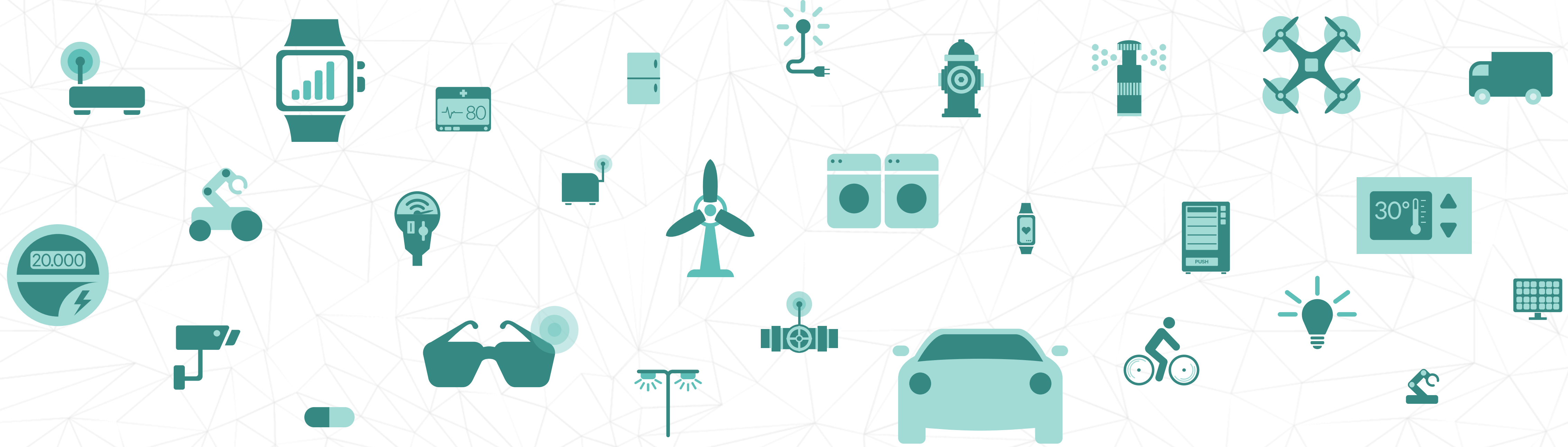
TOMORROW starts here.

Paving the path to Narrowband 5G with LTE Internet of Things (IoT)

Qualcomm Technologies, Inc.

June, 2016

IoT – a massive surge of smart, interconnected “things”



QUALCOMM®

Qualcomm Technologies, Inc. is a proven, trusted solution provider for IoT

Decades of industry experience

Broad portfolio of technologies

1B+ IoT devices shipped globally[1]

[1] Cumulative shipment using Qualcomm technologies; includes SoC, Cellular, Bluetooth, Wi-Fi , GNSS and PLC, stats as of April 2016

Connecting the IoT requires heterogeneous connectivity

Powered by global standards with seamless interoperability across multiple vendors

Cellular

Wi-Fi

Bluetooth

GNSS/Location

NFC

Powerline

Creating a connectivity fabric for everything

To support the wide range of IoT use cases with varying requirements

Throughput

Reliability

Node density

Coverage

Security

Cost

Battery life

Latency

Mobility

Cellular technologies enable a wide range of IoT services

>5B
IoT connections by 2025[1]

Smart cities
Lighting, traffic sensors, smart parking,…

Mobile health
Wearables, gateways, remote patient,…

Smart utilities
Smart grid, gas/water/ electric meters

Environmental monitoring
Agriculture, forecast fire/ air pollution sensors,…

Connected building
Security, video surveillance, smoke detectors,…

Connected industrial
Process/equipment monitoring, HVAC, …

Connected retail
Vending machines, ATM, digital ads,…

Asset tracking
Fleet management, pet/kid trackers, shipping,…

Ubiquitous coverage	Always-on connectivity	Reliable and secure	Global ecosystem

[1] Including Cellular & LPWA M2M connections, Machina Research, June, 2016

We are evolving LTE for the Internet of Things

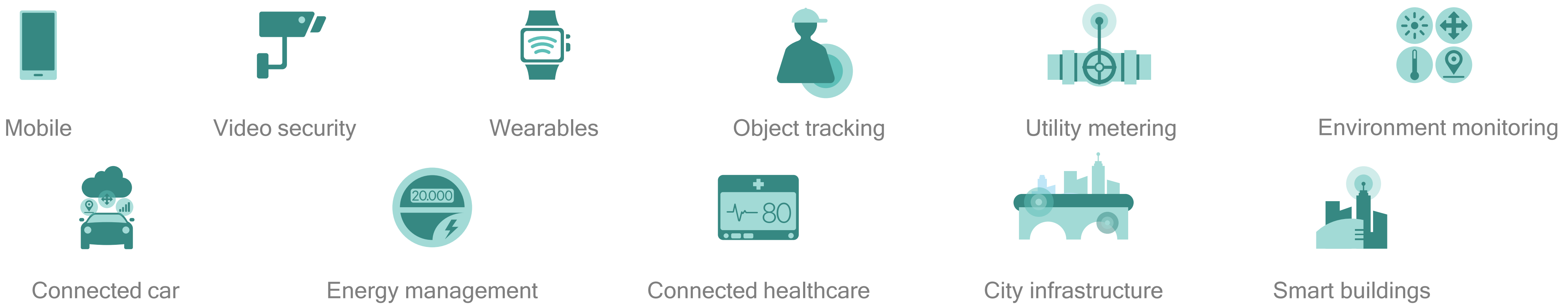
New narrowband technologies to more efficiently support IoT use cases

← Scaling up in performance and mobility

Scaling down in complexity and power →

Today | **New narrowband IoT technologies (3GPP Release 13+)**

LTE Cat-4 and above	LTE Cat-1	LTE Cat-M1 (eMTC)	Cat-NB1 (NB-IoT)
>10 Mbps	Up to 10 Mbps	Variable rate up to 1 Mbps	10s of kbps
n x 20 MHz	20 MHz	1.4 MHz narrowband	200 kHz narrowband



LTE IoT delivers significant value for LPWA[1] applications

Over non-3GPP solutions

Ubiquitous coverage
Established networks serving billions of connections worldwide

Scalability
To address the wide range of IoT use cases

Coexistence
Leverages existing and planned LTE infrastructure and spectrum

Mature ecosystem
Backed by global standards with a rich roadmap to 5G

Managed QoS
Based on licensed spectrum with a redundant network design

End-to-end security
Established/trusted security and authentication features built in

[1] Low-power, wide-area

Paving the path to 5G

NB-IoT is the foundation for Narrowband 5G; continuing to evolve in Release 14+

eMTC — Scales down LTE to address the broadest range of IoT use cases

NB-IoT — Optimizes to lowest cost/power for delay-tolerant, low-throughput IoT use cases

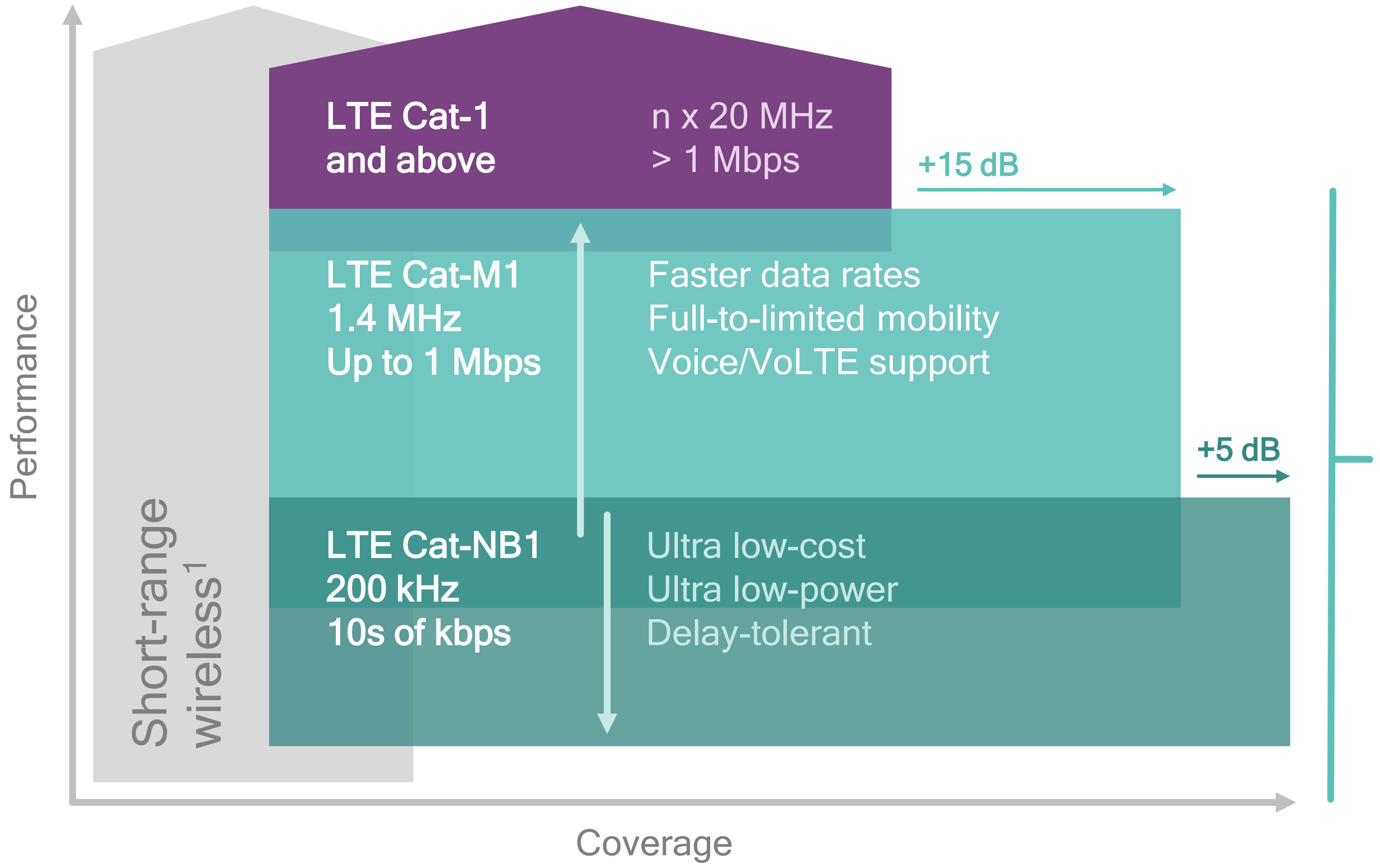
NB-5G — 3GPP 5G NR further enhances massive IoT with new capabilities such as RSMA[1] & multi-hop mesh

[1] Resource Spread Multiple Access

Delivering new narrowband LTE IoT technologies

As part of 3GPP Release 13

Two new LTE IoT technologies, one unified LTE platform



LTE Cat-M1 (eMTC)

Broadest range of IoT capabilities with support for advanced features, e.g. voice support

Many IoT devices can benefit from multi-mode operations to optimize for different traffic profiles and RF conditions

LTE Cat-NB1 (NB-IoT)

Scalable to lowest cost/power for delay-tolerant, low-throughput IoT use cases, e.g. remote sensors

[1] Examples include Bluetooth, Wi-Fi, NFC, and others

LTE IoT reduces complexity, extends battery life & coverage

Through optimizations to both the air interface and core network

Reduced complexity

Narrowband operation (1.4 MHz or 200 kHz) plus further device and core network complexity reductions

Multi-year battery life

Enhanced power save modes and more efficient signaling, e.g. extended DRX sleep cycles

Deeper coverage

Achieve up to 20 dB increase in link budget for hard-to-reach locations via redundant transmissions

Higher node density

Signaling and other network optimizations, e.g. overload control, to support a large number of devices per cell

Coexistence with today’s mobile broadband services

Leveraging existing infrastructure and spectrum

New LTE IoT device categories reduce LTE complexity

To enable low-cost modules optimized for small, infrequent data transmissions

	LTE Cat-1 (Today)	LTE Cat-M1 (Rel-13)	LTE Cat-NB1 (Rel-13)
Peak data rate	DL: 10 Mbps UL: 5 Mbps	DL: 1 Mbps UL: 1 Mbps	DL: ~20 kbps UL: ~60 kbps
Bandwidth	20 MHz	1.4 MHz	200 kHz
Rx antenna	MIMO	Single Rx	Single Rx
Duplex mode	Full duplex FDD/TDD	Supports half duplex FDD/TDD	Half duplex FDD only
Transmit power	23 dBm	20 dBm[1]	20 dBm[1]

Higher throughput, lower latency, full mobility

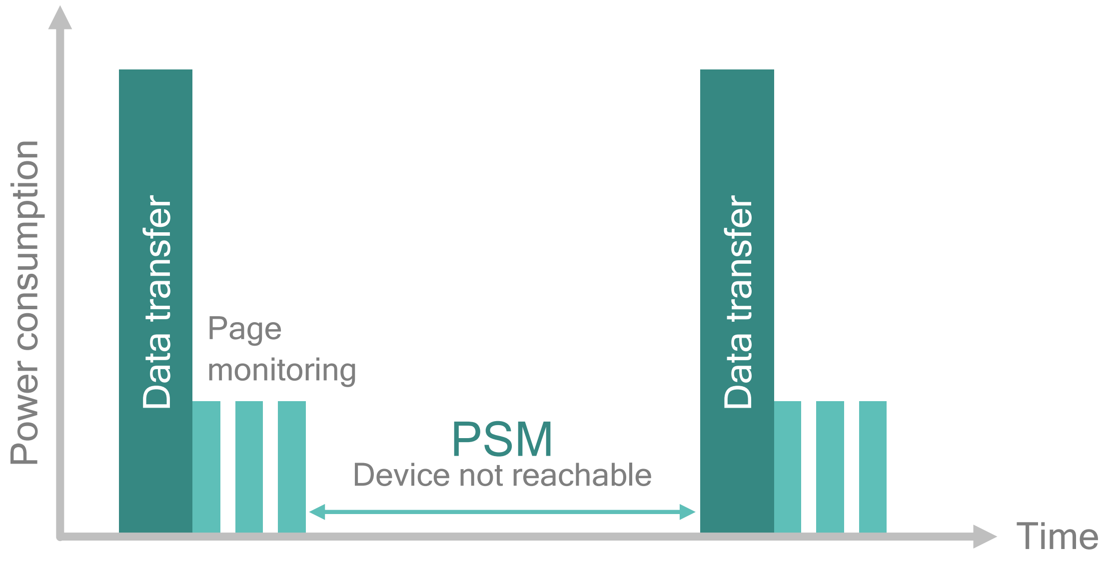
Simplified RF hardware

Reduces baseband complexity and decreases memory

[1] Integrated PA possible

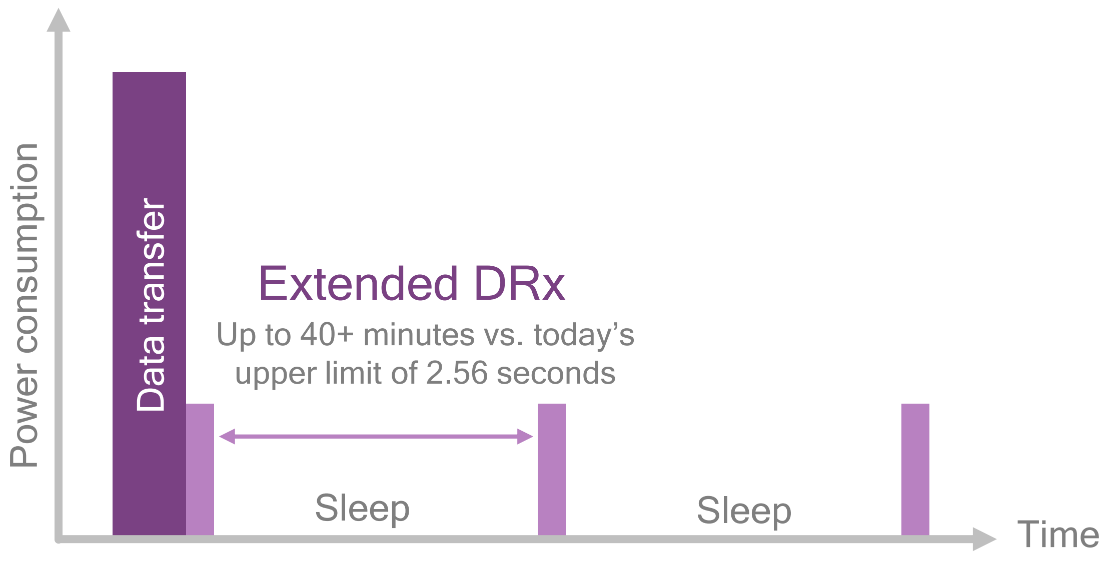
Delivering multi-year battery life

Devices wake up on a per-need basis; stay asleep for minutes, hours, even days



Power save mode (PSM)

Eliminates page monitoring between data transmissions
For device-originated or scheduled applications, e.g., smart metering, environmental monitoring



Extended discontinuous receive (eDRx)

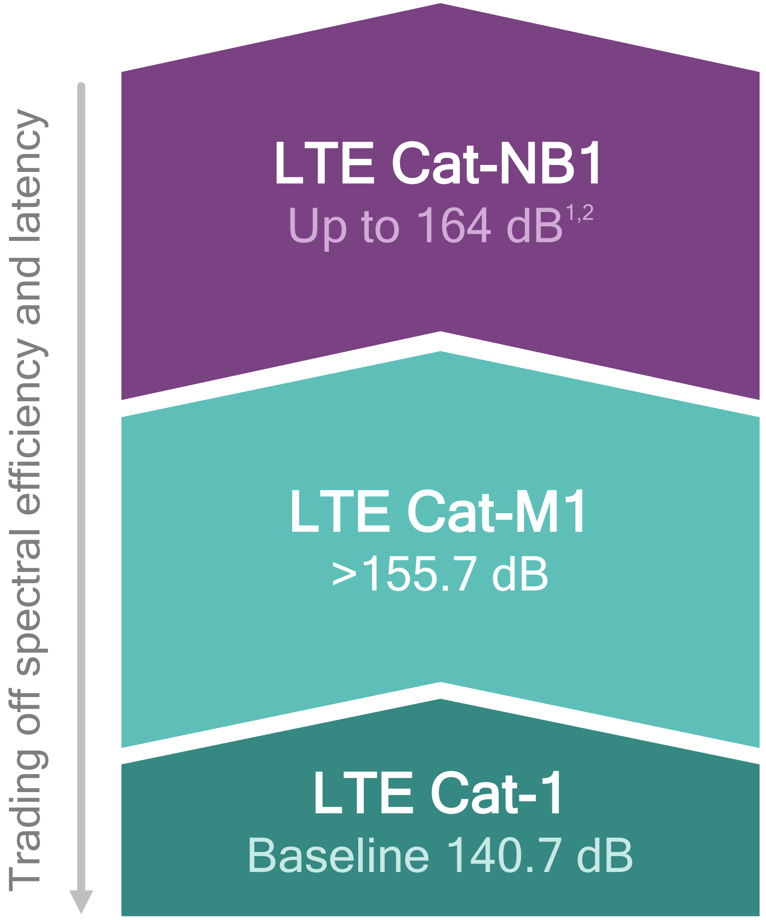
Extends time between monitoring for network messages
For device-terminated applications, e.g., object tracking, smart grid

Also features such as reduced complexity and less channel measurements extend battery life

Note: PSM and eDRx applicable to both Cat-M1 and Cat-NB1; may also be applied to LTE Cat-1 and above

Numerous technology enablers for deeper coverage

To reach challenging locations, e.g. penetrating more walls & floors



Cat-NB1 only

- Further relaxed requirements, e.g. timing
- Low-order modulation, e.g. QPSK
- Option for single-tone uplink transmissions

Cat-M1 and Cat-NB1

- Repetitive transmissions & TTI bundling for redundancy
- Narrowband uplink transmissions

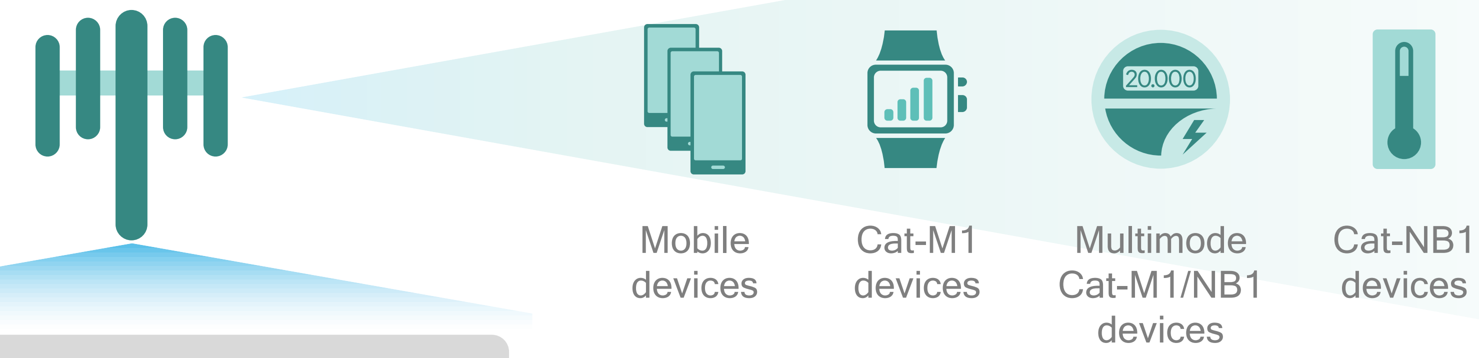
[1] Link budget; [2] At least for standalone operation mode

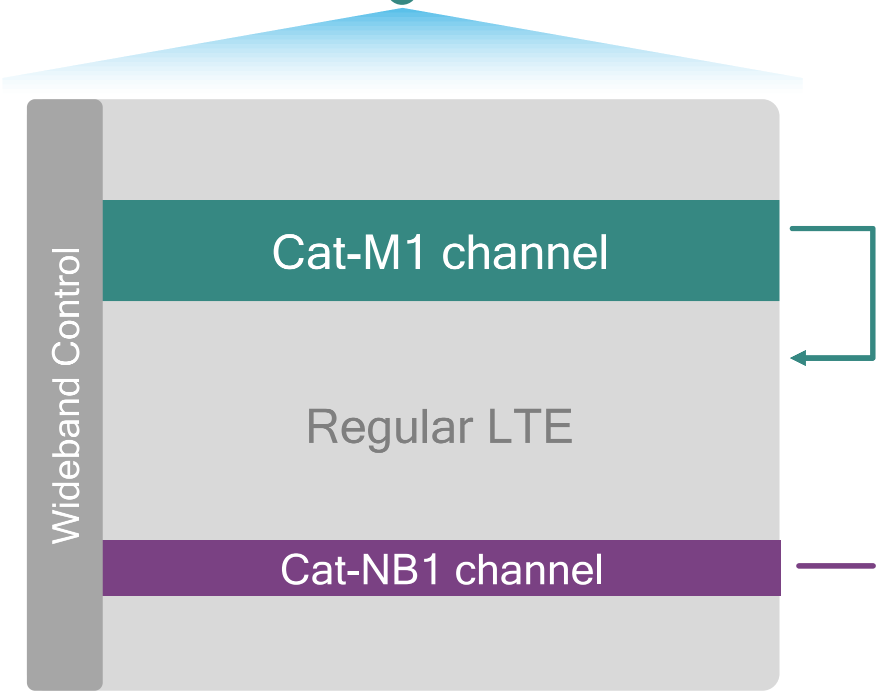
Coexisting with today's LTE services

Cat-M1 and Cat-NB1 can leverage existing LTE infrastructure and spectrum

<0.1%

Data capacity for IoT traffic based on sample scenario[1]





Reuse center 6 PRB[2] for synchronization; data channel can operate across entire LTE band for most efficient coexistence with today's traffic

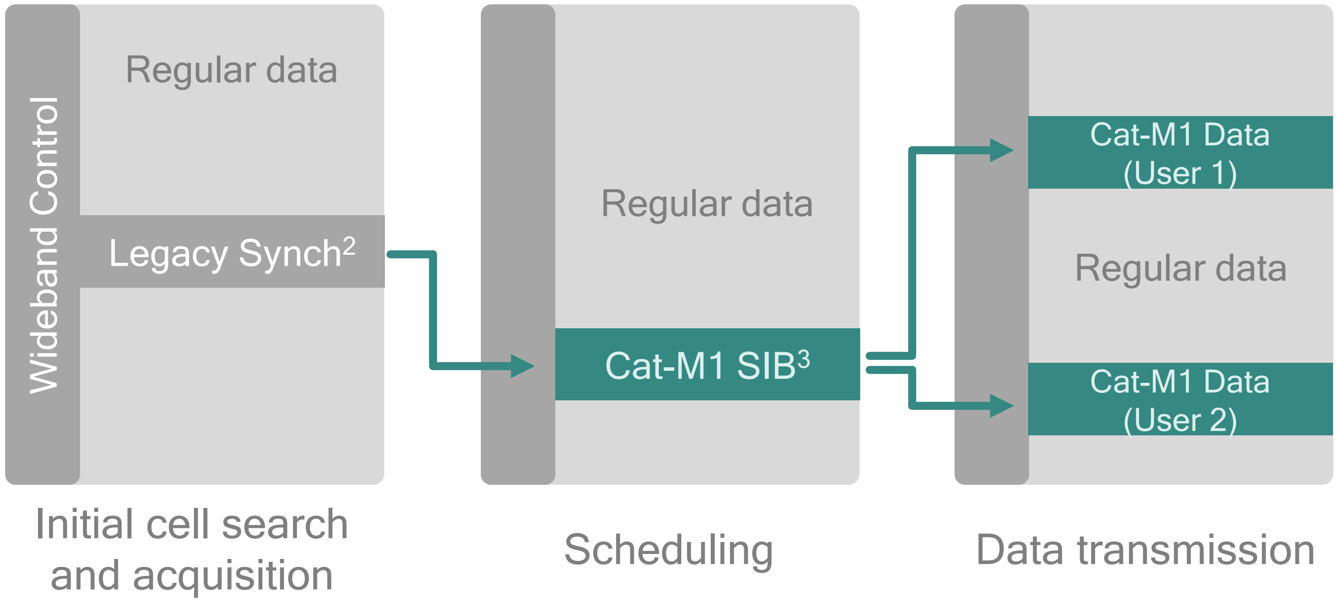
New synchronization anchor channels are in restricted narrowband locations; may also be deployed standalone[3] or in LTE guard band

[1] Assumptions: ISD Urban - 500m, 3 cells per site, Channel b/w 10MHz, Cell capacity: DL 14Mbps, UL 9.6Mbps; Traffic types include data and commands for Electric Meter, Water Meter, Security Panel, HVAC - Residential, Outdoor Street Light, Off Street Parking Meter, Parking Space Sensor, Water Assets; 100% of traffic assumed in 6hr. busy period; [2] Physical Resource Block; [3] Including re-farming of GSM spectrum

Cat-M1 (eMTC) efficient coexistence with today's services

Narrowband operation of 1.4 MHz[1] across entire LTE band

Supports FDD or TDD spectrum



Co-existence

Time and Frequency-Division Multiplexing between LTE IoT and today's existing services, e.g. mobile broadband

Flexible capacity

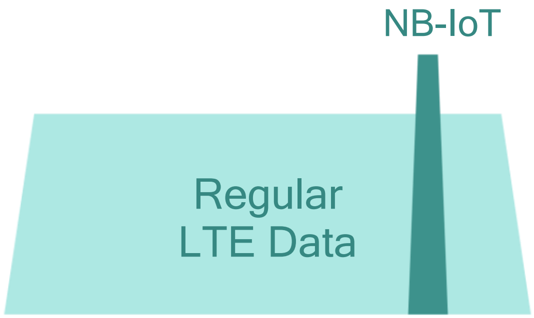
Multiple narrowband regions with frequency retuning to support scalable resource allocation between LTE IoT and non-IoT traffic[4]

[1] 1.08 MHz used by the network to transmit 6 RBs in-band; [2] PSS/SSS/PBCH; [3] SIB (System Information Block); [4] Also supports frequency hopping within LTE band for diversity

Cat-NB1 (NB-IoT) flexible deployment options

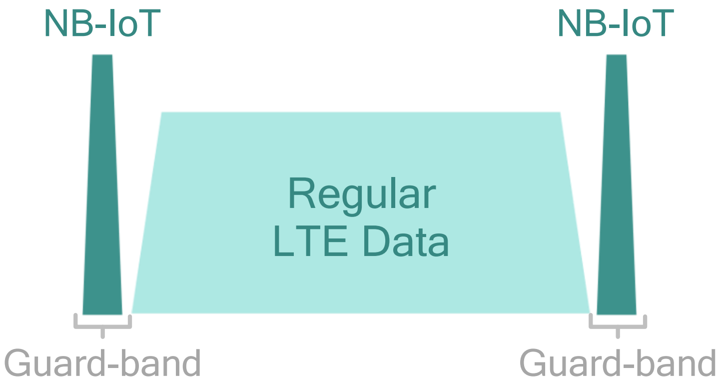
Dedicated NB carrier – supports FDD spectrum only in Rel-13

In-band



Utilizing single Resource Block (180 kHz) within a normal LTE carrier

Guard-band



Utilizing unused resource blocks within a LTE carrier's guard-band

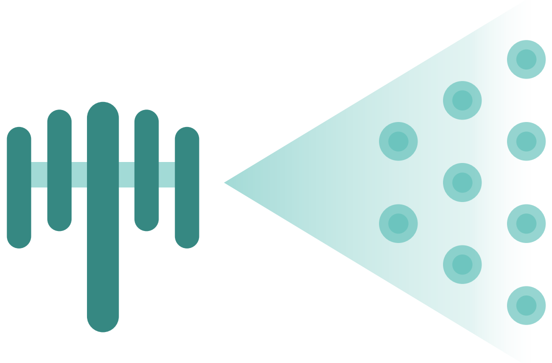
Standalone

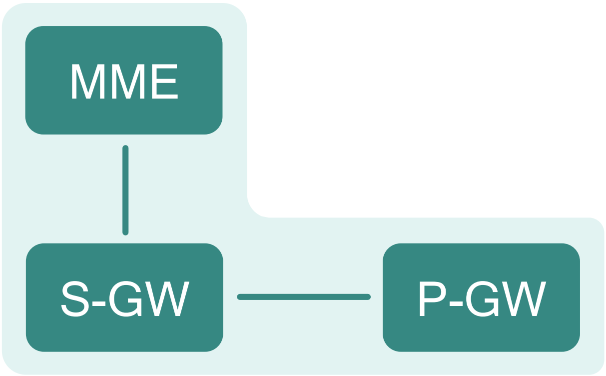
Utilizing stand-alone 200 kHz carrier, e.g. re-farming spectrum currently used by GERAN systems

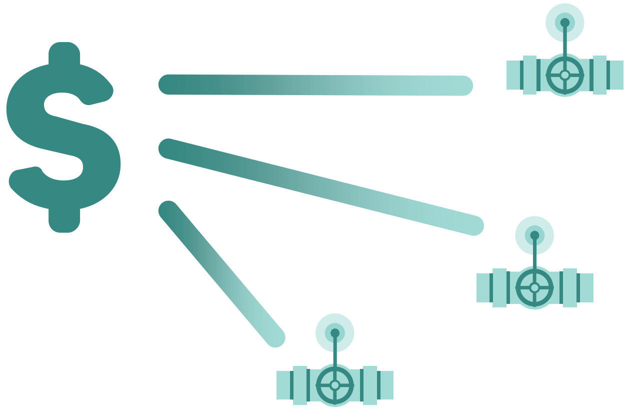
New optimized NB-IoT synchronization, control, and data channels

Delivering IoT optimizations to the network architecture

Also part of 3GPP Release 13







More efficient signaling

To support a larger number of devices per cell with new features such as group-based paging and messaging

Simplified Core Network (EPC-lite)

Reduced functionality, e.g. limited mobility and no voice, makes possible for integrating network functions into a single entity

Enhanced resource management

Such as optimizations to allow a large set of devices to share the same subscription, e.g. all the water meters in a city

Optional optimizations so that mobile operators can effectively balance CAPEX vs. OPEX decisions

Small cells add value to LTE IoT deployments

Venues | Industrial | Residential | Enterprise/Buildings | Cities

Improved coverage

Bringing the network closer for deeper reach indoors and more reliable connectivity

Longer battery life

Allowing devices to reduce uplink transmit power, minimizing overall power consumption

More deployment options

Leveraging neutral hosts to provide IoT connectivity in shared/unlicensed spectrum (e.g. MulteFire)

Providing an end-to-end LTE IoT platform

To simplify the deployment and management of IoT services

Simplified device development

Development platforms
Certified modules
Certified devices

Optimized LTE connectivity

Reduced complexity
Lower power
Deeper coverage

Simplified service management

Billing/cost mgmt.
Remote provisioning
Embedded SIM (eUICC)
Real-time diagnostics

Simplified network architecture

Reduced functionality
Optimized signaling
Virtualization

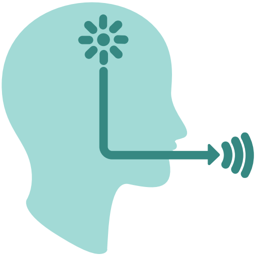
Simplified application development

Standardized protocols
Interoperability
End-to-end security
e.g. oneM2M

Roadmap to 5G will bring even more opportunities for the Internet of Things

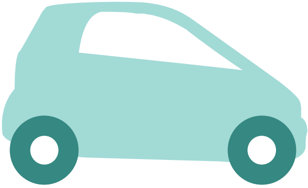
We are continuing to evolve NB-IoT beyond Release 13

The foundation to Narrowband 5G



VoLTE

Adding voice and options to support lower latency services



Mobility

Enabling devices to monitor and report channel conditions for inter-cell handovers

Positioning

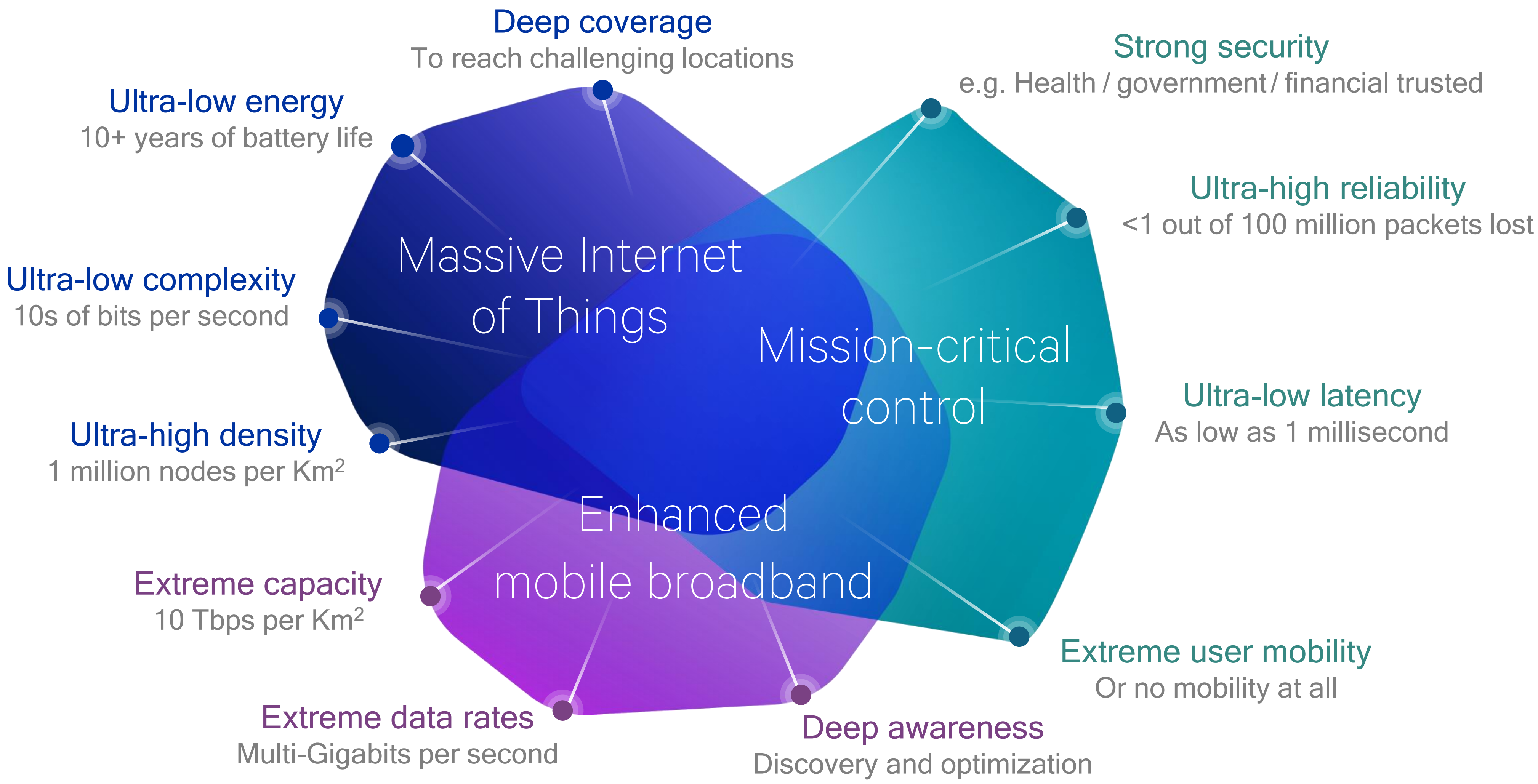
Providing location services for use cases such as mobile asset tracking and emergency call

Broadcast

Allowing more efficient OTA firmware update for large number of devices, e.g. sensors, meters

We are also designing a new 5G NR air interface

5G NR will be scalable to an extreme variation of IoT requirements

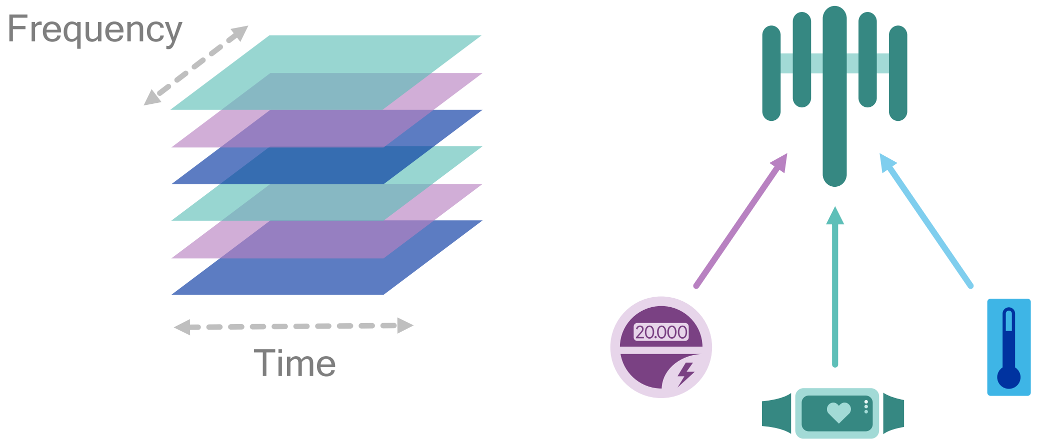


Based on target requirements for the envisioned 5G use cases

Bringing new capabilities for the massive IoT

Grant-free uplink

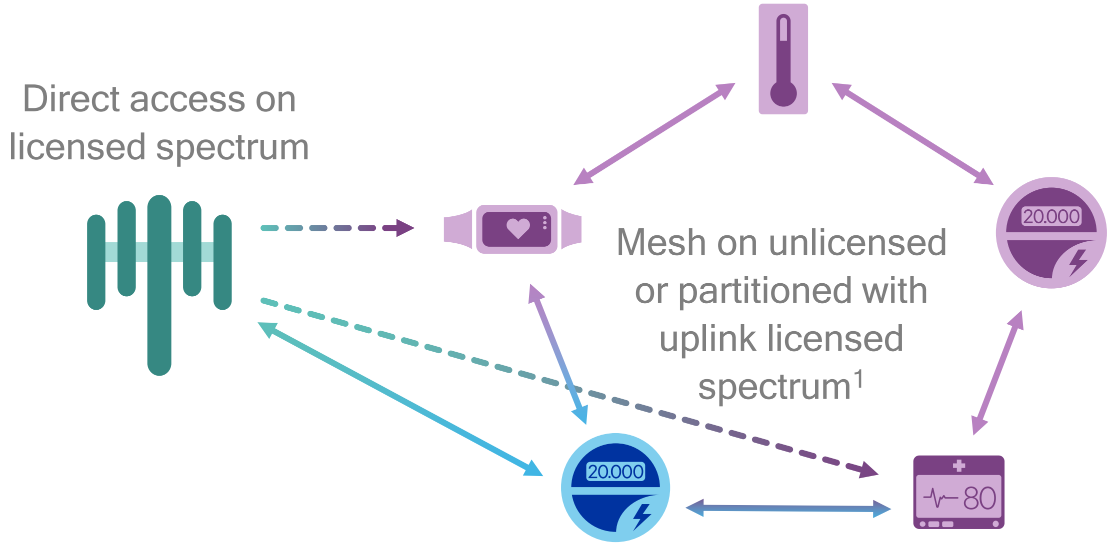
Resource Spread Multiple Access (RSMA)



Enables asynchronous, non-orthogonal, contention-based access that is well suited for sporadic uplink transmissions of small data bursts common in IoT use cases

Coverage extension

Multi-hop mesh with WAN management

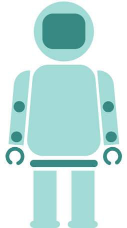


Overcomes uplink coverage issues due to low-power devices and challenging placements by enabling uplink data relayed via nearby devices; opportunity to reduce power/cost even further

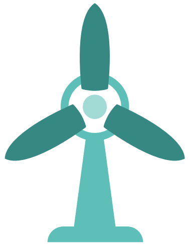
[1] Greater range and efficiency when using licensed spectrum, e.g. protected reference signals . Network time synchronization improves peer-to-peer efficiency

Also enabling new mission-critical control IoT services

Autonomous vehicles



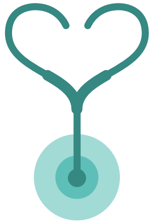
Robotics



Energy/ Smart grid

Aviation

Industrial automation



Medical

1ms e2e latency

Faster, more flexible frame structure; also new non-orthogonal uplink access

Ultra-high reliability

Ultra-reliable transmissions that can be time multiplexed with nominal traffic through puncturing

Ultra-high availability

Simultaneous links to both 5G and LTE for failure tolerance and extreme mobility

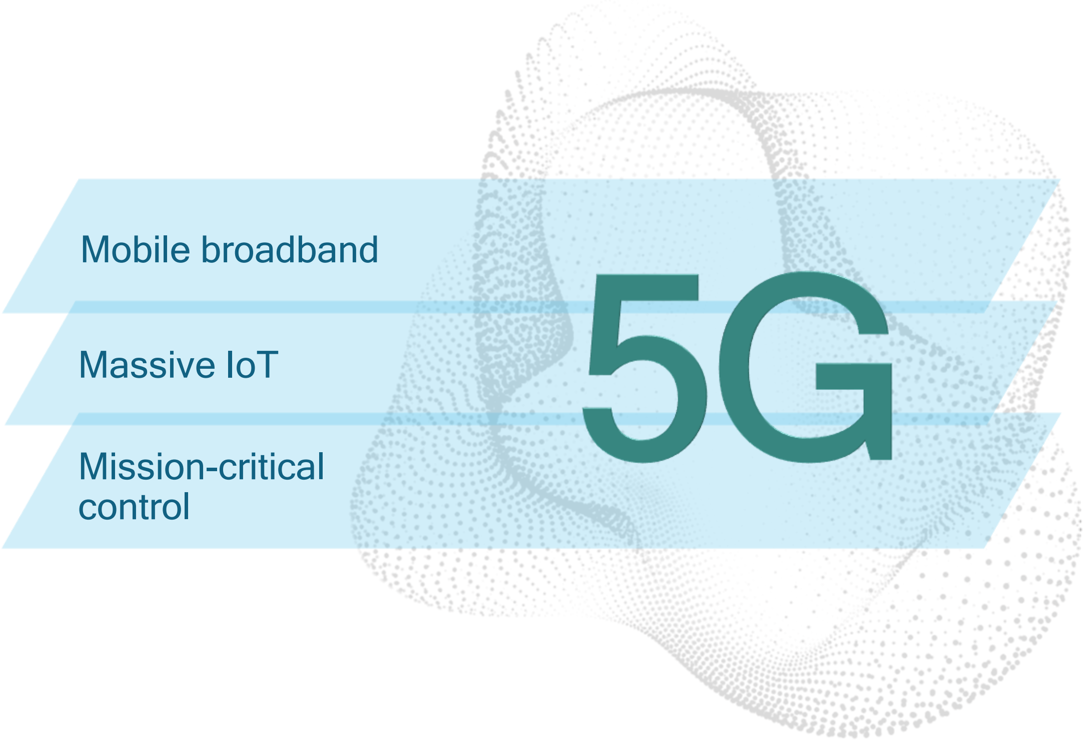
Strong e2e security

Security enhancements to air interface, core network, & service layer across verticals[1]

[1] Also exploring alternative roots of trust beyond the SIM card

Flexible 5G network architecture brings additional benefits

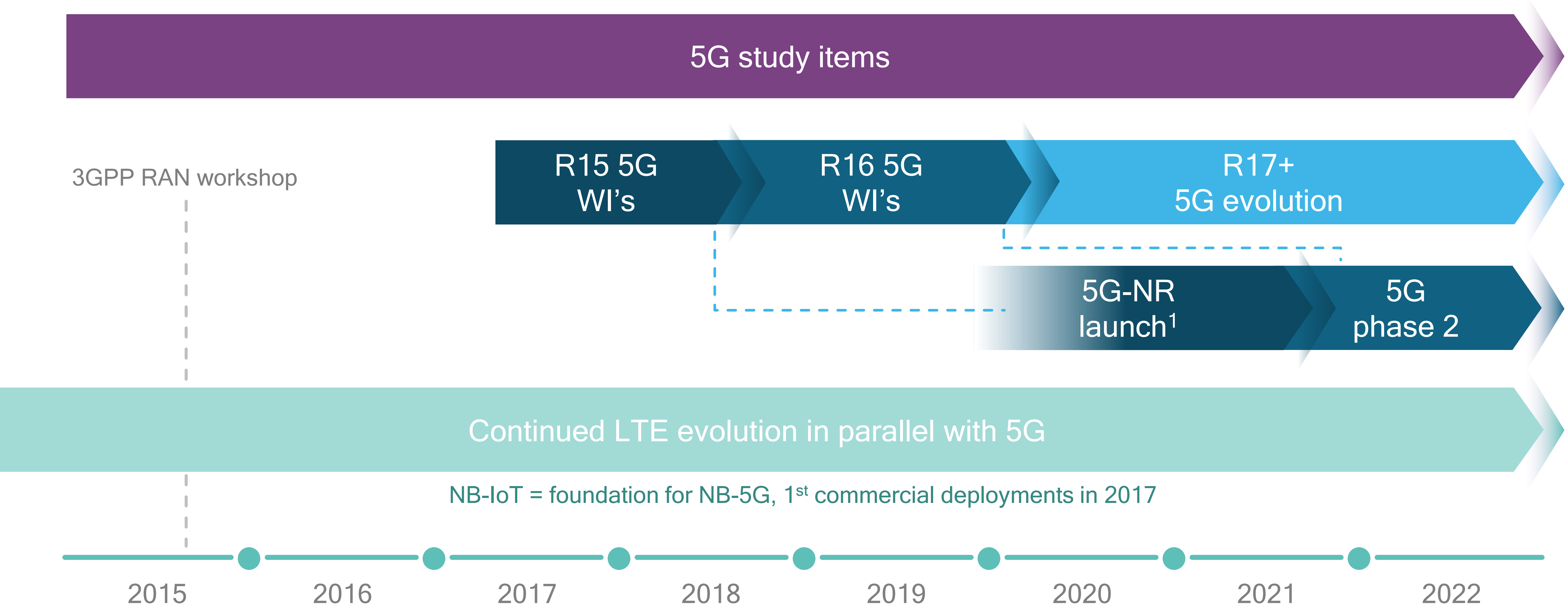
Leveraging virtualized network functions to create optimized network slices



- Configurable end-to-end connectivity per vertical
- Modular, specialized network functions per services
- Flexible subscription models
- Dynamic control and user planes with more functionality at the edge
- Multi-access core network will provide connectivity to LTE, NB-IOT, and 5G IoT

Better cost/ Energy efficiency	Optimized performance	Flexible business models	Dynamic creation of services

5G standardization progressing for 2020 launch



Learn more at: www.qualcomm.com/5G

Note: Estimated commercial dates; [1] Forward compatibility with R16 and beyond

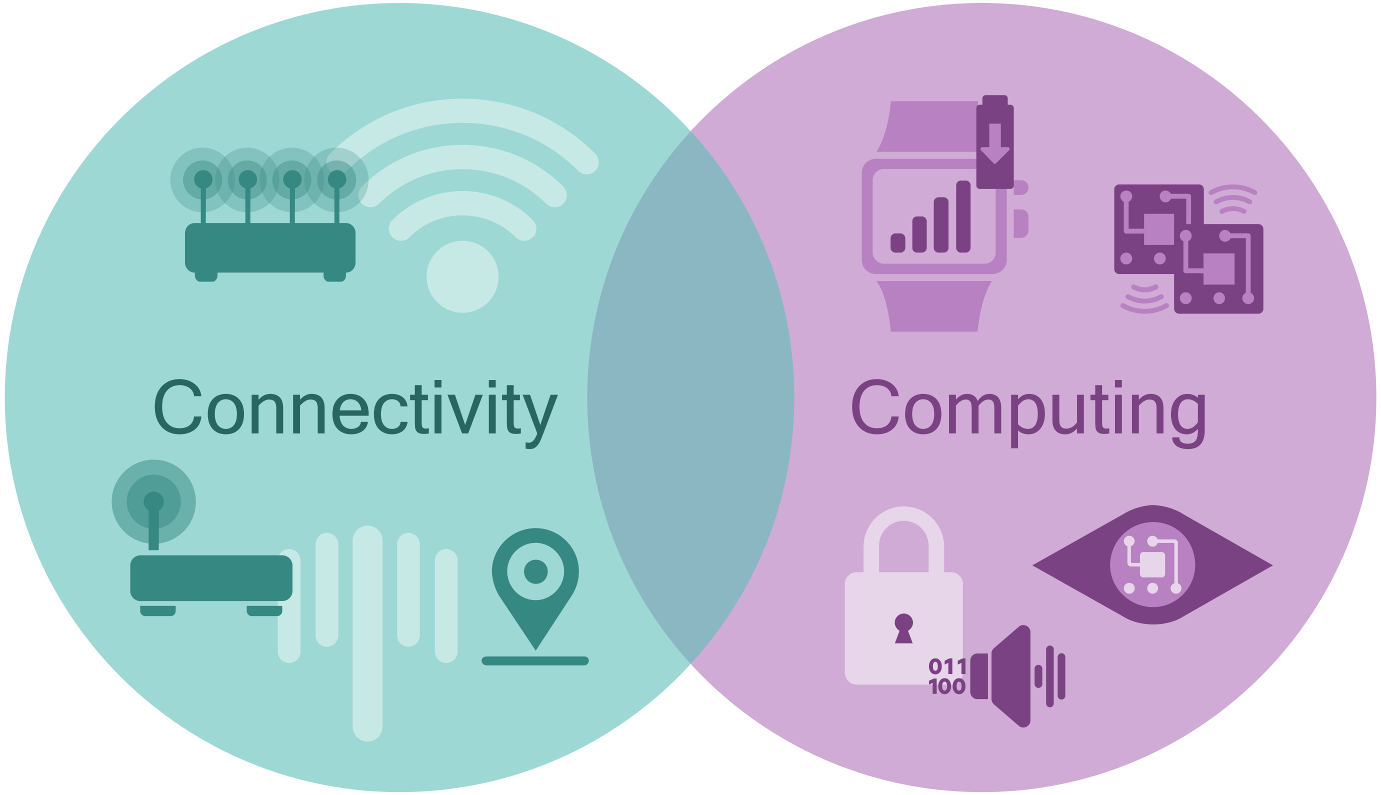
Qualcomm is uniquely positioned to connect the Internet of Things

An established leader today –
pioneering tomorrow's technologies

Delivering a broad portfolio of technologies for the IoT

To meet diverse connectivity and computing requirements

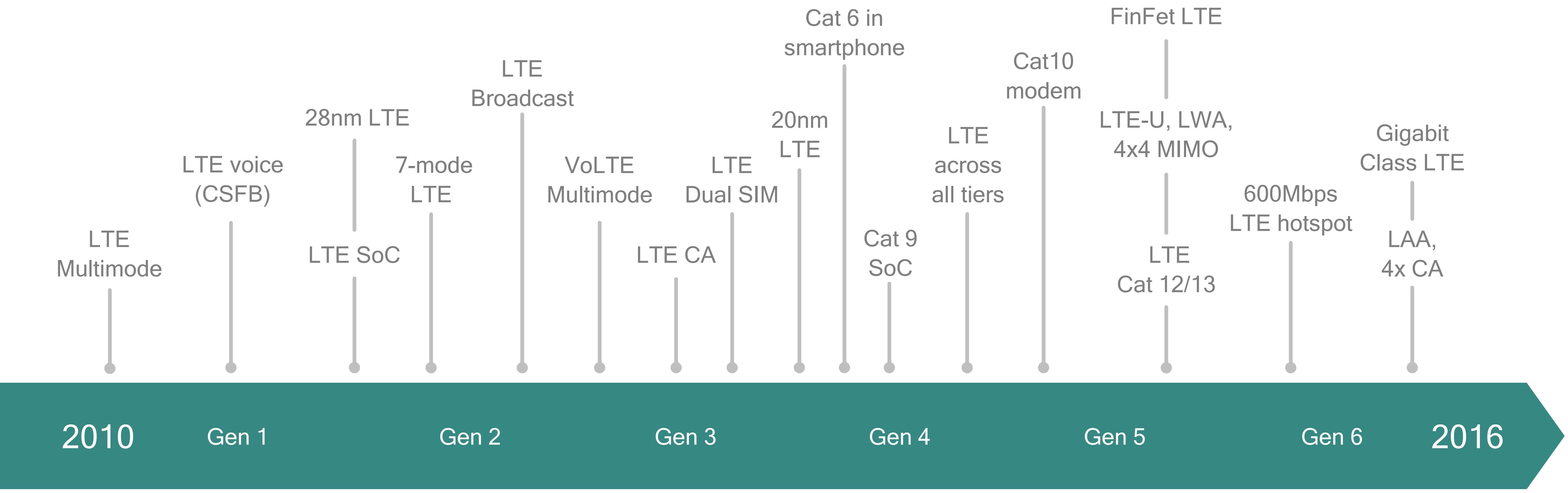
Bluetooth Smart
Bluetooth Mesh
802.11ac
802.11ad
802.11n
DSRC
NFC
3G
4G LTE
5G
Powerline
GNSS/Location



Cognitive computing
Camera processing
Audio processing
Sensor core
Security
CPU
GPU
DSP
Media processing
Augmented reality
Display processing
Power management

Qualcomm Technologies' LTE platform leadership

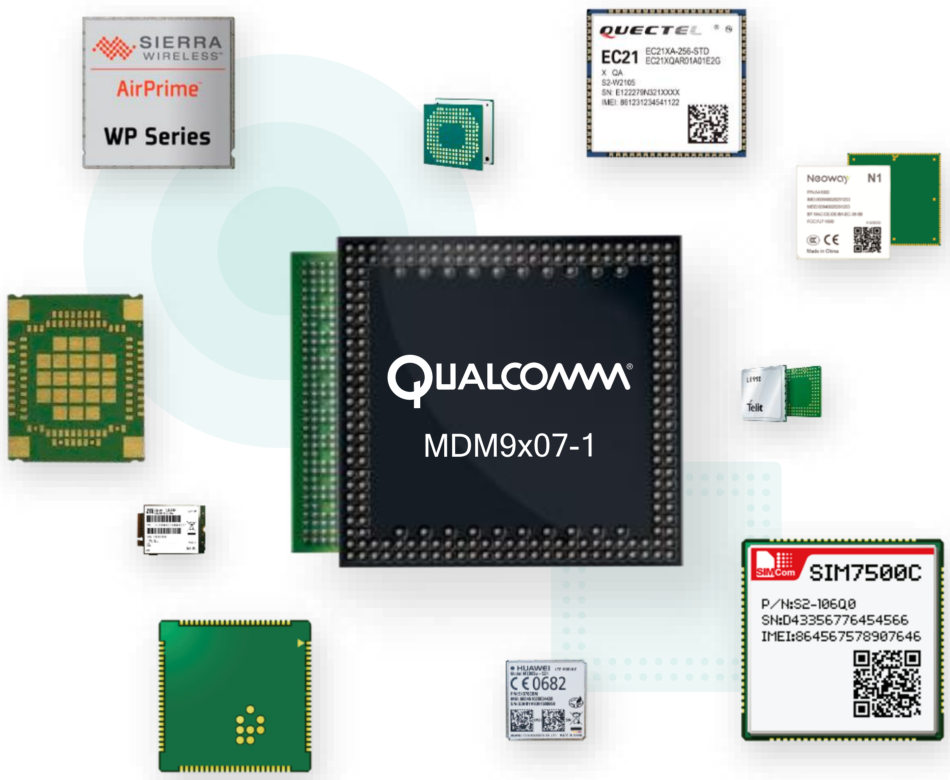
A history of industry firsts



Qualcomm Technologies modem generation and feature

Delivering 3G and 4G LTE solutions for the IoT today

Established ecosystem partners with proven global solutions



Qualcomm MDM9x07-1: LTE Cat-1 modem for the Internet of Things

- 4G/3G global band support (multimode/multiband)
- Highly integrated to reduce cost / complexity
- PSM enabling up to 10+ years battery life
- Scalable to add voice, Wi-Fi, BT capabilities
- Hardware-based security

More than 100 design wins from over 60 manufacturers[1]

[1] Includes Qualcomm Snapdragon X5 LTE (9x07) and MDM9x07-1 modem, as of June 2016

Driving new LTE IoT technologies towards commercialization

Rel-13 specification now complete for LTE Cat-M1 (eMTC) and Cat-NB1 (NB-IoT)

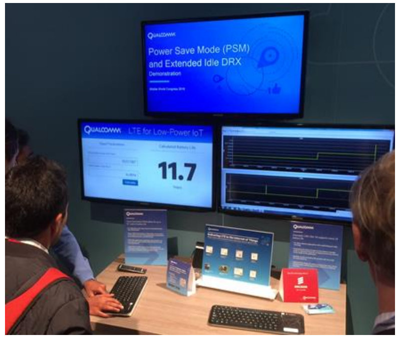
3GPP A GLOBAL INITIATIVE

Standards leadership

Main contributor to eMTC and NB-IoT features

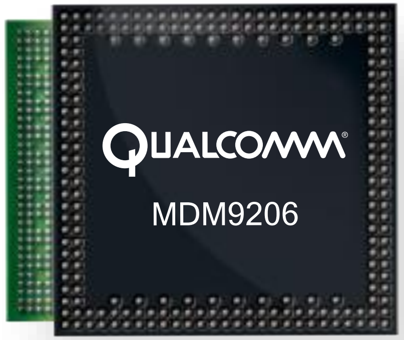
Harmonized Industry on narrowband IoT (NB-IoT) specification

Pioneering work on future IoT technologies, e.g. multi-hop to extend uplink coverage



Prototyping new technologies

PSM & eDRx simulations and system tests, as demonstrated at MWC 2016

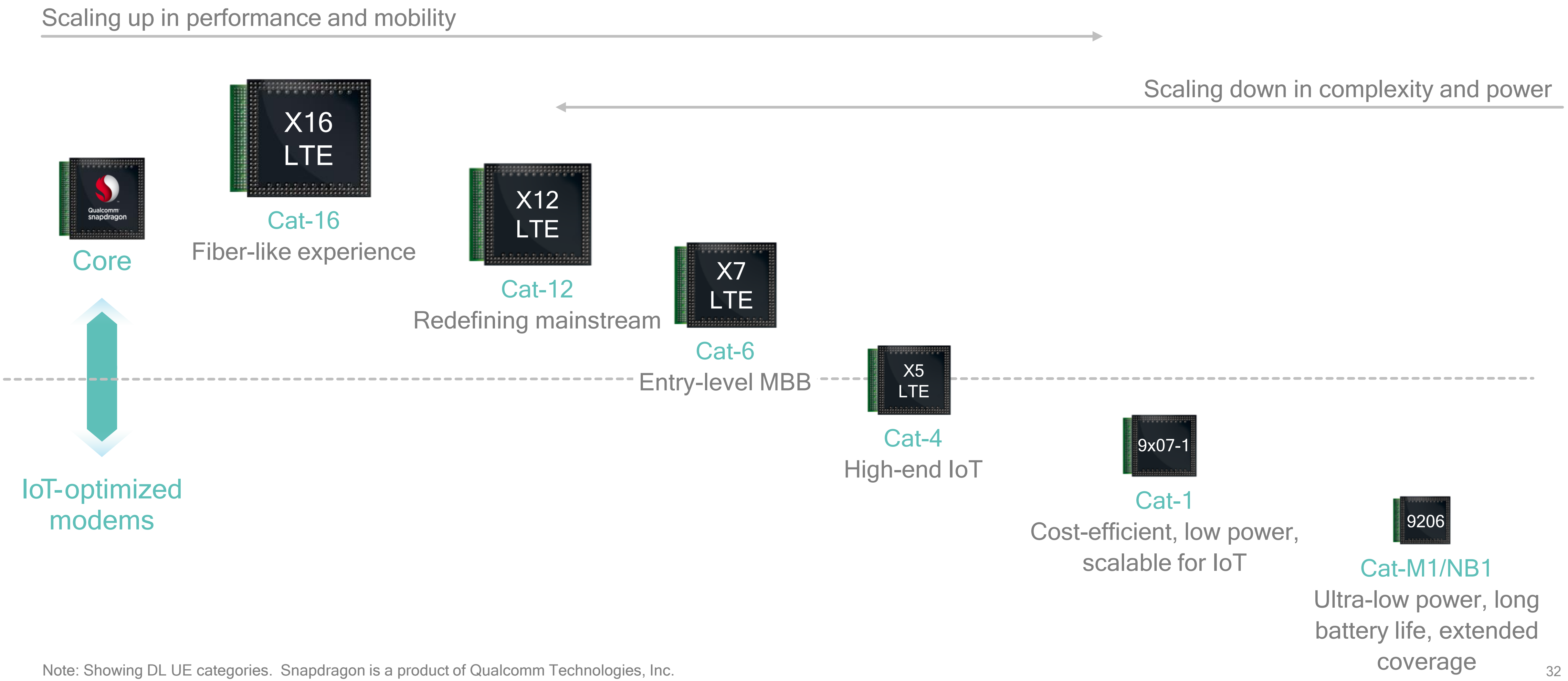


Qualcomm MDM9206 Flexible chipset platform

Common hardware solution to enable Cat-M1 and/or Cat-NB1

Delivering a scalable roadmap across all tiers & segments

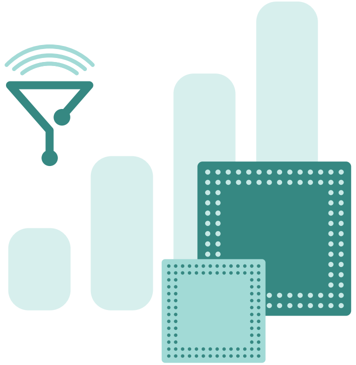
LTE from gigabit to micro-amp



Note: Showing DL UE categories. Snapdragon is a product of Qualcomm Technologies, Inc.

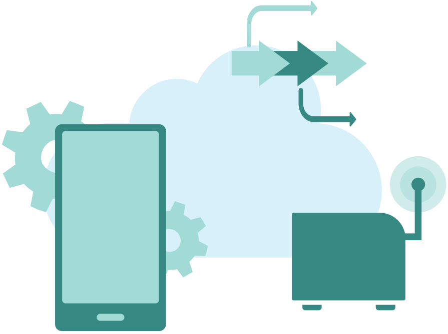
Leading the world to 5G

Investing in 5G for many years—building upon our leadership foundation



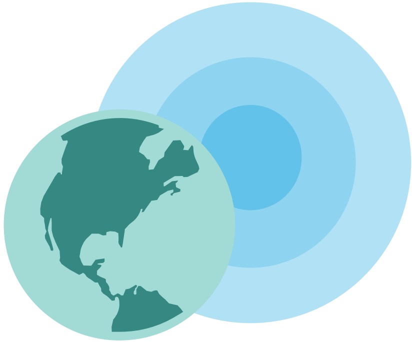
Wireless/OFDM technology and chipset leadership

Pioneering new 5G technologies to meet extreme requirements



End-to-end system approach with advanced prototypes

Driving 5G from standardization to commercialization



Leading global network experience and scale

Providing the experience and scale that 5G demands

In summary

LTE is evolving to deliver a unified, scalable IoT platform that brings significant benefits over non-3GPP LPWA solutions

Delivering new narrowband IoT technologies (Cat-M1/NB1) to lower complexity, increase battery life, and deepen coverage – establishes the foundation for Narrowband 5G

Roadmap to 5G will bring even more opportunities for the Internet of Things including new mission-critical services

Qualcomm is uniquely positioned to connect the Internet of Things and is leading the world to 5G

Learn more at: http://www.qualcomm.com/LTE-IoT

Questions? - Connect with Us

www.qualcomm.com/wireless

BLOG

www.qualcomm.com/news/onq

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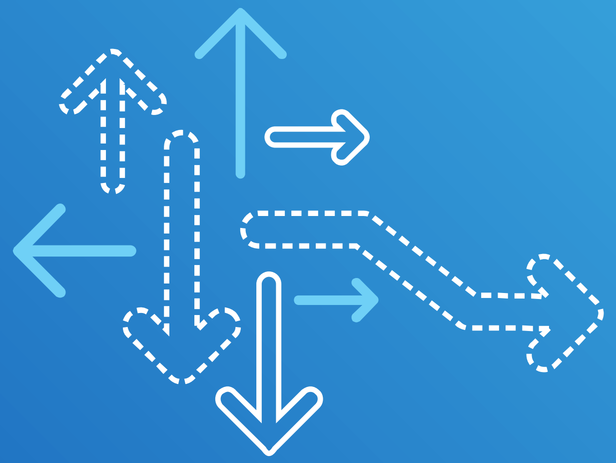
http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp

http://www.slideshare.net/qualcommwirelessevolution



Thank you

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Information-Centric IoT over 5G

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(Huawei Research Lab, Santa Clara)

(Fall 2015 Research Review, Winlab/Rutgers, Dec 4th, 2015)

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Agenda

- 5G Drivers
- 5G-IoT Requirements
- Evolving from IP → ICN
- 5G Network Softwarization
- 5G-ICN Architecture
- LEAN CIBUS for 5G
- Unified ICN Protocol Proposal
- VSER Platform
- ICN-IoT Prototyping

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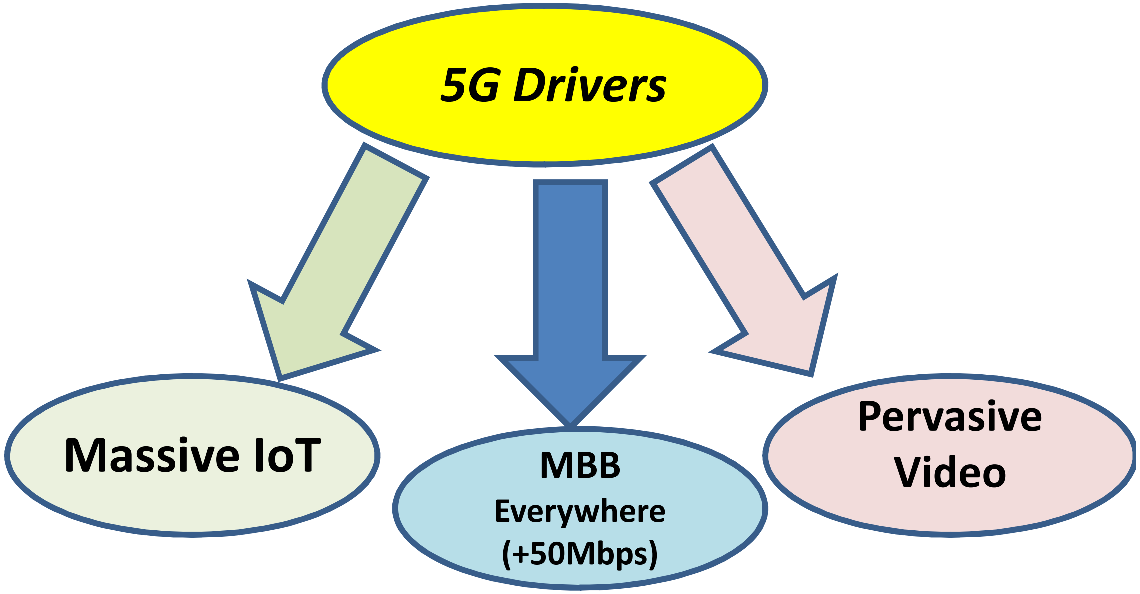
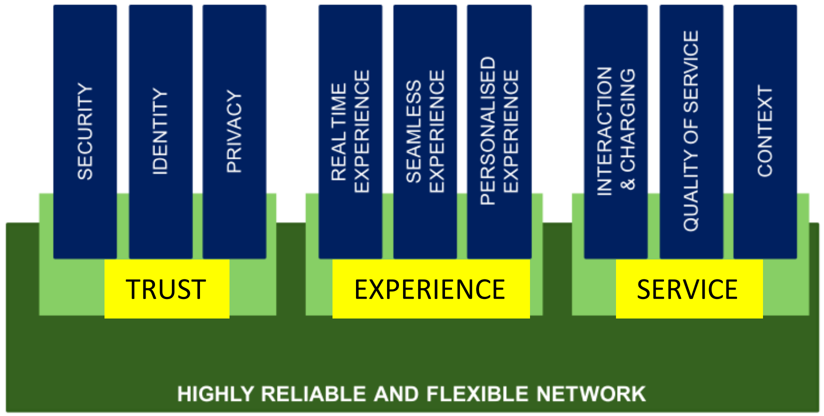
5G Drivers

Requirements have been set in [1]

- **Heterogeneous Devices** and Applications
  - Traditional and Emerging IoT (M2M))
- **Enable Service Centric Networking**
  - Allow new Business Models
  - XaaS (Naas/SaaS/PaaS)
  - Not only Connectivity Services
  - **Service Platform for Users and ASPs**
  - **Personalized and Contextualized**
- **Low end-to-end Latency**
  - 1-10ms depending on the application
- **High Capacity and Data Rate**
  - >1000x Capacity, >10-100x Bandwidth
- **High Reliability**
  - Security, Mobility, Disaster Scenarios





5G Value Creation Capabilities

[1] NGMN White Paper on 5G: https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

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5G-IoT Requirements [1]

- **Low-Cost/Long-Range/Low-Power as well as Broadband MTC**
  - Smart Weareables
    - Key Challenge is overall **management of the number of devices as well as data and applications**.
  - Sensor Networks
    - Low-Cost/High battery life requirement
    - Light weight networking/applications
  - Mobile video Surveillance
    - High degree of Mobility
- **Many other IoT related classes of applications identified**
  - Extreme Real-time Communications
    - Tactile Internet
  - Lifeline Communications
  - Ultra-Reliable Communications
    - Automated Traffic Control and Driving
    - Collaborative Robots
    - eHealth ; Remote Surgery…

[1] [1] NGMN White Paper on 5G: https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

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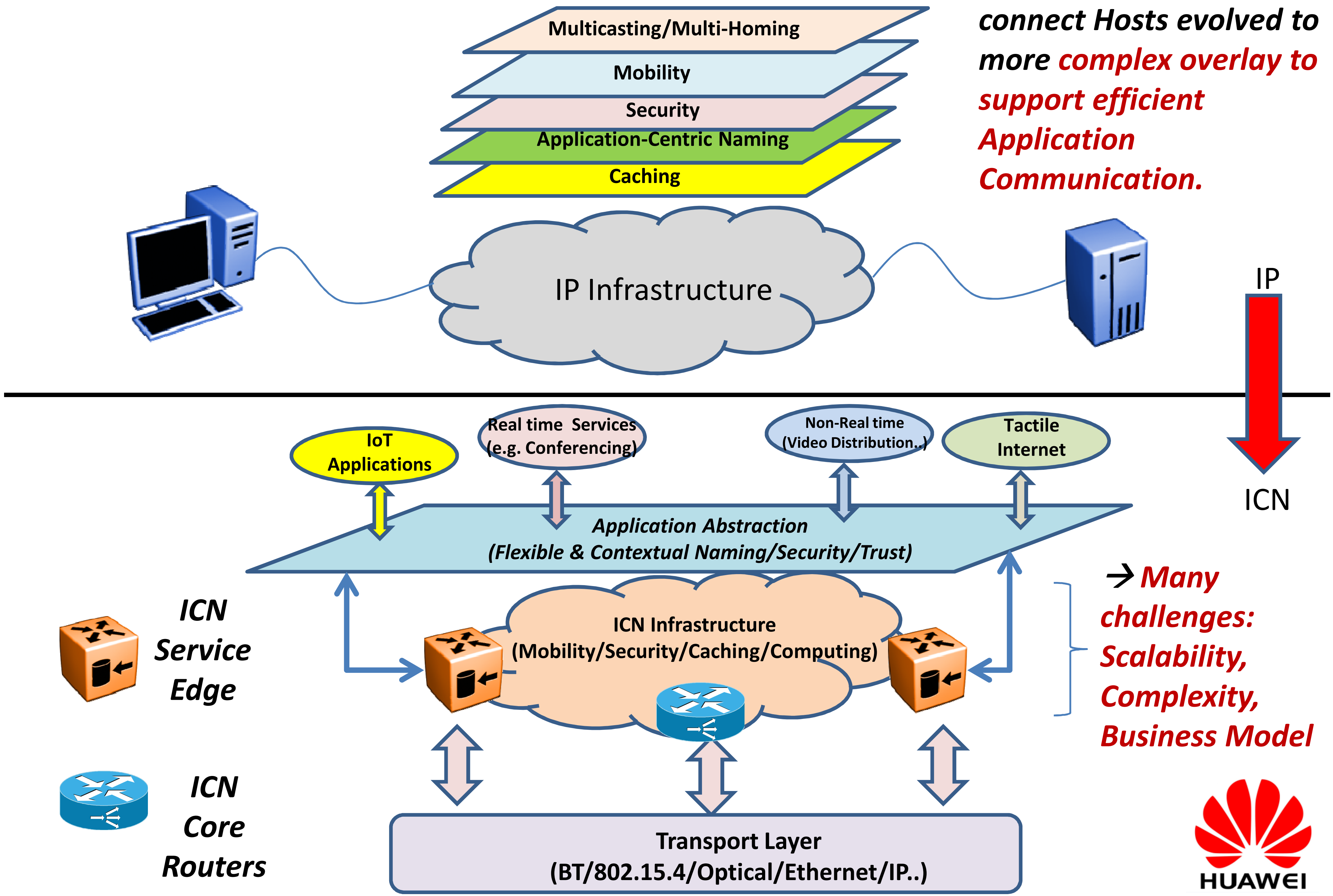
- Evolving from IP to ICN
- ICN for IoT

From Add-On to Build-In

→ *Original Internet to connect Hosts evolved to more complex overlay to support efficient Application Communication.*



→ *Many challenges: Scalability, Complexity, Business Model*

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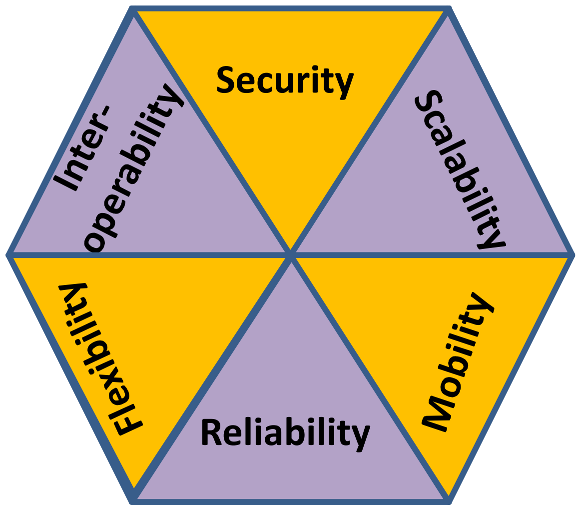
Why ICN Architecture is a Better Candidate for IoT [1] ?

- Inter-operability
  - Unified Naming: Content/Devices/Services; Application-Centric and Persistent
    - Hierarchical/Secure/Hybrid
  - Information/Device/Service/Content level Inter-operability
  - Enable Network layer based on "Name Abstraction", more suitable for IoT than "Host Abstraction"
  - Contextual Communication
- Security and Privacy
  - Packet based on Names enable Object Security
  - Security level is adaptive based on Trust requirements
- Scalability
  - ID/Locator Split, flexible communication either on ID or ID+Locator
  - Less host-based forwarding State in the Routers
- Flexibility
  - Communication Models (PULL/PUSH/PUB-SUB/Multicast/Anycast)
  - Flexible Packet Format (IoT + Infrastructure)
  - Self Organization
  - Adhoc and Infrastructure Mode
  - Hierarchical Processing
  - Resource Constraint
- Reliability
  - Caching/Storage Integral part of the design
  - Increases Data Availability improving IoT Service Reliability
- Mobility
  - Consumer mobility achieved from caching
  - Late binding allows Seamless Mobility
  - Handles Producer mobility (could be significant in IoT)

IoT Requirements



[1] "**Requirements and Challenges for IoT over ICN**", https://tools.ietf.org/html/draft-zhang-icnrg-icniot-requirements-00

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Recent IoT Industry Stacks

AllJoyn Architecture (Qualcomm)

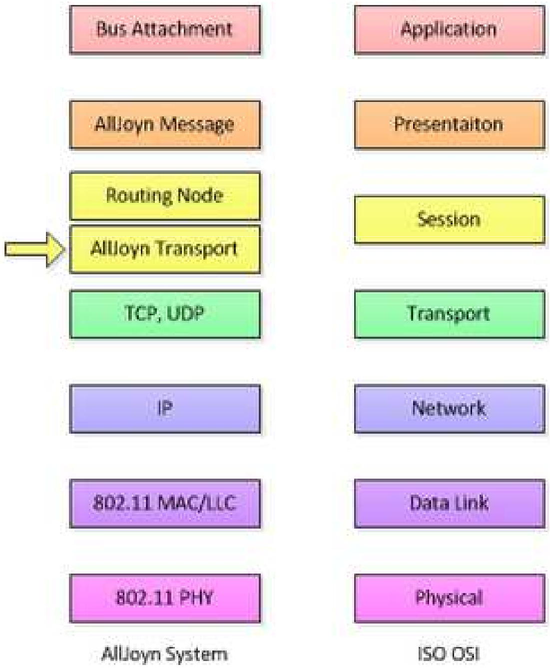
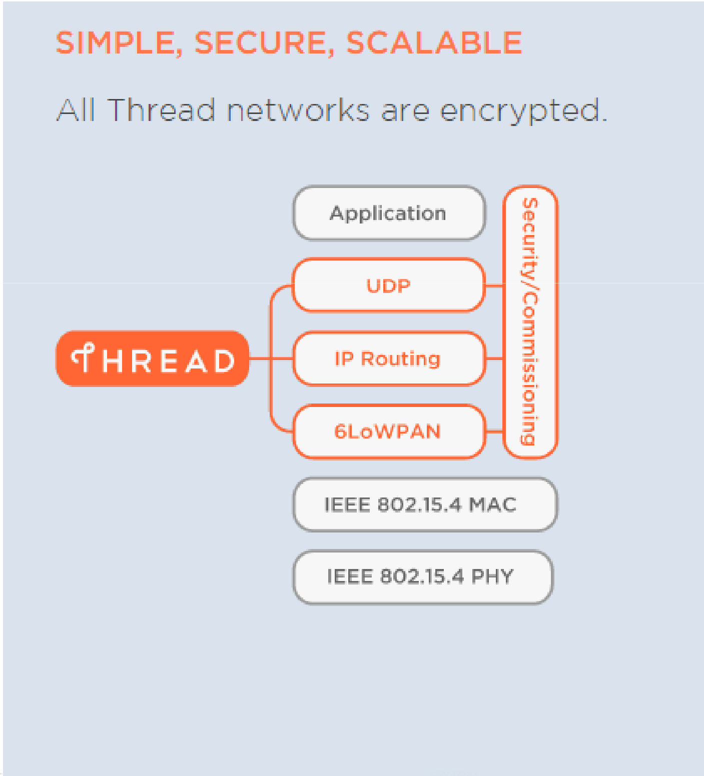
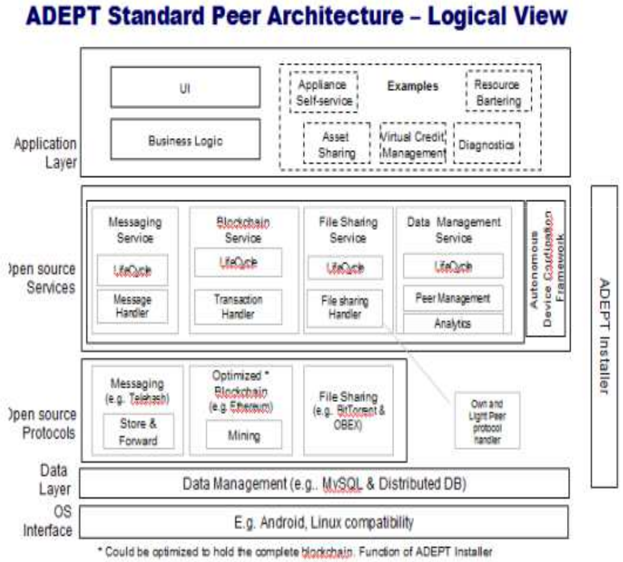


Figure: AllJoyn transport in the ISO/OSI 7-layer model

Thread Architecture (Google)



IBM ADEPT



[1]Telehash (DHT), Blockchain, Ethereum, BitTorrent,

Architectures focuses on Naming, Discovery, D2D, Content Distribution, Secure Transactions, and Business Logic, which are subset of features offered by ICN.

Emerging IoT Architectures, reminder of the Pre-IP days. ICN encompasses all this and more (Multicasting/Mobility/Caching/Computing etc.)

[1] IBM ADEPT White Paper, https://archive.org/details/pdfy-esMcC00dKmdo53-_

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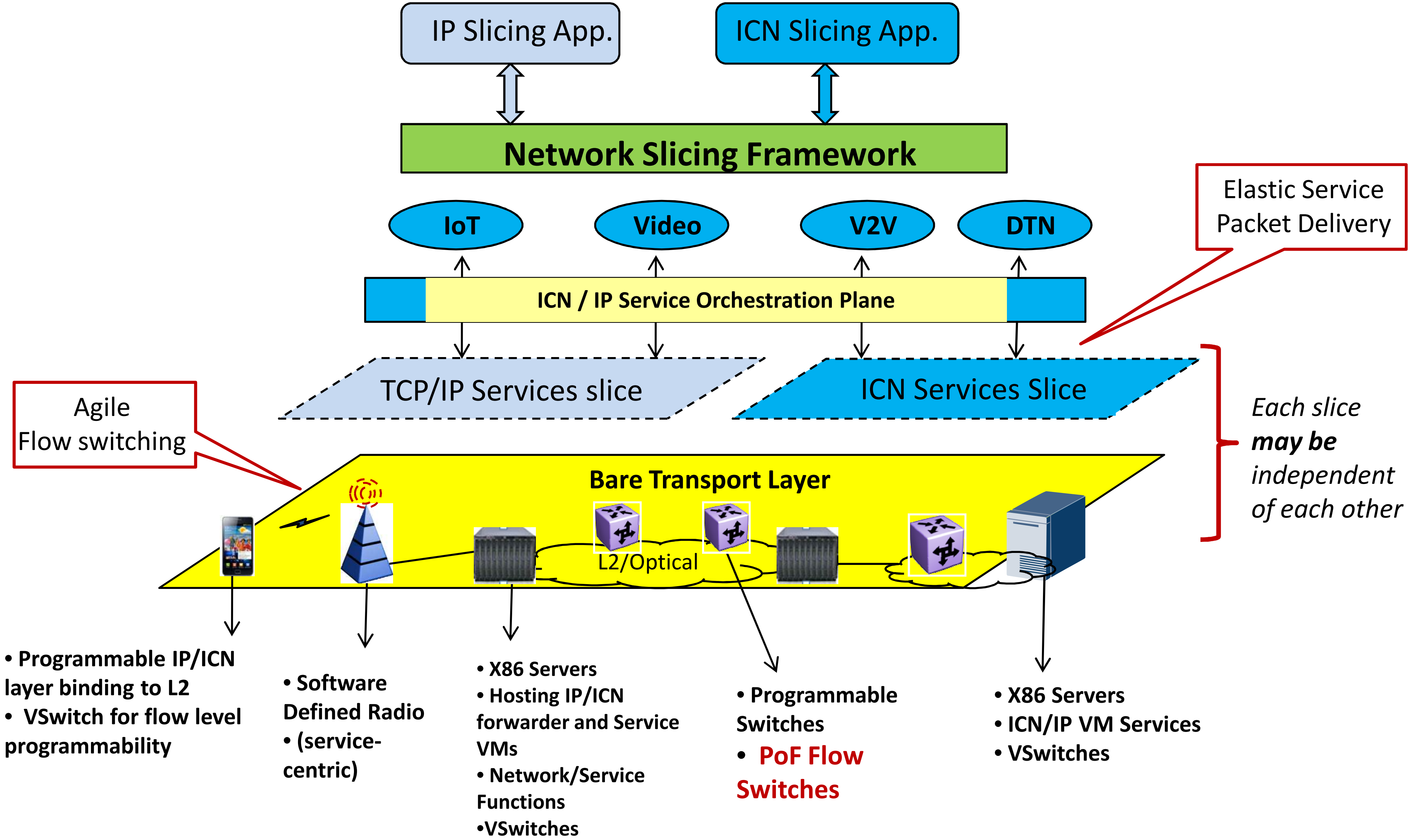
- **5G Network Softwarization**
- **5G-ICN Architecture**

5G Network Softwarization Framework [1]

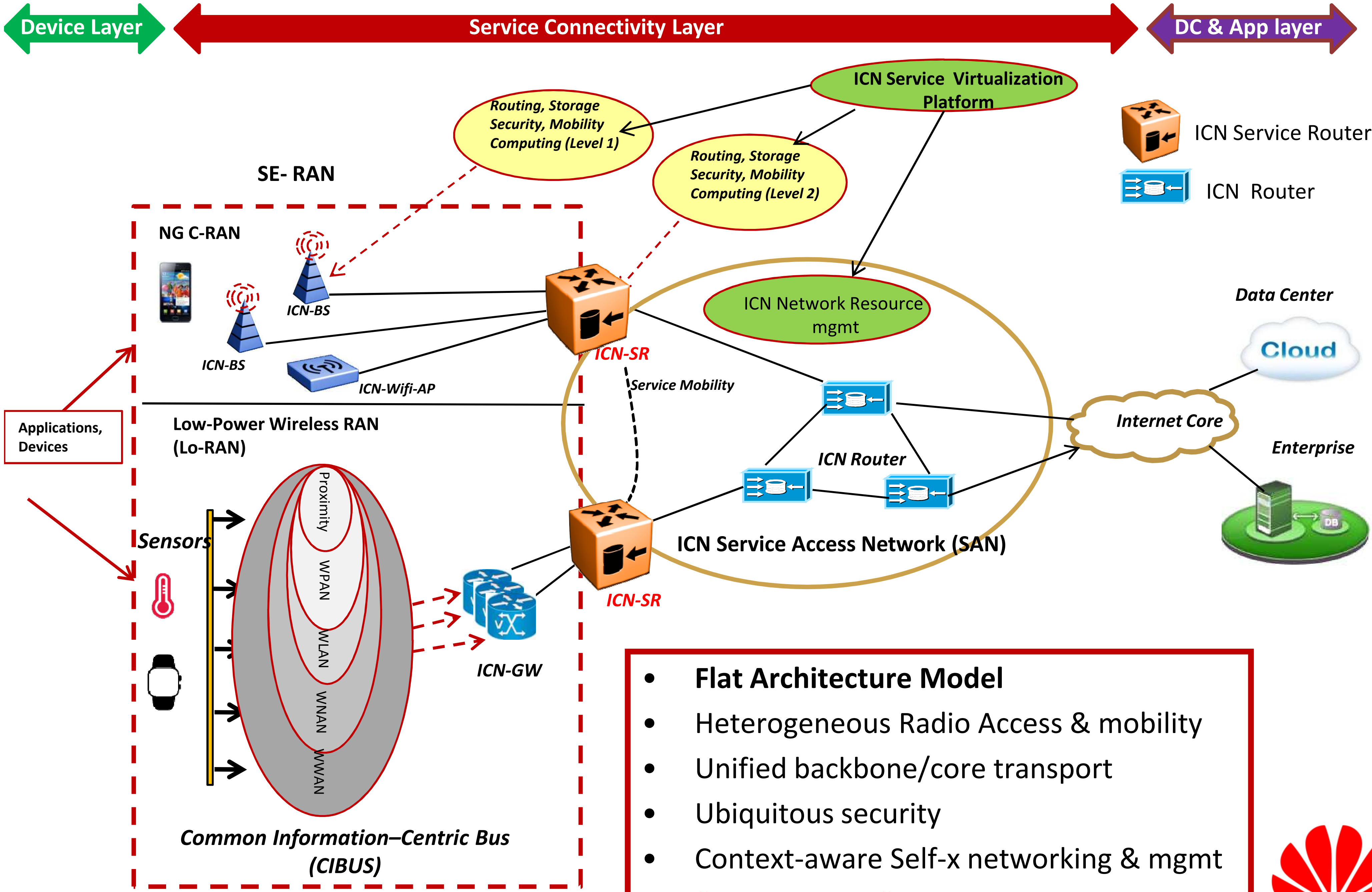


- The objective is to create elastic ICN/IP slices and its associated control/service plane on demand.
- Identified are also some of the end-to-end technology enablers

[1] ITU, FG, IMT 2020 – "Network Standardization Requirement for 5G"

SE-RAN & ICN-SAN: Service-Enabled 5G Architecture

(ITU FG IMT-2020, 09/2015)



- **Flat Architecture Model**
- Heterogeneous Radio Access & mobility
- Unified backbone/core transport
- Ubiquitous security
- Context-aware Self-x networking & mgmt
- "One Protocol"

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SE-RAN Functional Features

- **NG C-RAN**
  - Flat Architecture and Heterogeneous Radio Access
  - **ICN Edge Cloud** Intelligence all the way to the BS and UE
  - **Distributed Routing, Storage/Caching, Computing, Mobility Functions**
  - Application/Services Binds to Names
  - **Name Based Routing/Forwarding**
  - Mobility/Migration
  - **Multi-homing/Multicasting**
  - **Data based Security and Trust** (Enforceable on the Infrastructure)
  - D2D/P2P/MP2MP
  - Adaptable and Service Centric (Low Latency, High Throughput etc.)
- **Common Information-Centric BUS (CIBUS)**
  - Addresses the need for next 50B IoT devices on 5G
  - Middleware over Constrained and Non-Constrained Devices
  - **Enables Self-X (Discovery, Routing, Service Point Attachment)**
  - **Contextualized Device/Service Discovery & Processing**
  - Heterogeneous Radios (WPAN,LORAN, WLAN etc.)
  - Local/Global Naming Service
  - Hierarchical Data Processing
  - **Security/Trust Management**
  - PUB/SUB System for Large scale Content Distribution
  - Open-APIs for Inter IoT system connectivity

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ICN Service Access Network (ICN-SAN)

- **ICN Service Enabled Network Infrastructure**
  - ICN Service Edge Routers
    - Host Arbitrary Service Functions
    - Caching/Storage/Computing features
  - ICN Routers focusing on High Performance Routing/Forwarding
- **Service Virtualization Platform**
  - ICN-Centric Network Slicing/Virtualization and Resource Management
  - Fine Grained Cache/Compute/Bandwidth/Spectrum Resource Management for end-to-end Service Delivery
  - ICN based Network Abstraction
    - Software-Defined Name Based Routing
  - Opportunistic Placement of Service Functions and Inter-Connection to Adapt to varying user behavior and dynamics
  - Service Orchestration involving UE, Servers and VSERs, E-NodeB (end-to-end)

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LEAN CIBUS for 5G

- *Light Weight*
- *Elastic*
- *Agile*
- *Networking*

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Elastic PDU TLV format (Under Discussion): For IoT and Large MTUs

- "draft-ravi-elastic-icn-packet-format-00", IETF/ICRG Draft

E=0	Ver (3b)	Msg Type (4b)
Hop Limit (1B)		
Length (Max:255B)		
Type = ICN-Msg-Type	Length = ICN-Msg-Length	
ICN Message		

3B Fixed Header

ICN Message

IoT Friendly

E=1	Ver (3b)	Msg Type (4b)
Hop Limit (1B)		
Length (1B) = 0x00 (if >255 B)		
Extended Header TLV Container		
Optional Length TLV		
Other Optional TLVs..		
ICN Message		

3B Fixed Header

Extended Header TLV Container

High Capacity Transport Friendly

e.g. SigFox Cellular [1] Technology (12B Payload)

E=0	Ver (3b)	Msg Type (4b)
Hop Limit (1B)		
Length		
1+0 TLV	Name (1B)	
1+0 TLV	Content (3B)	
1+0 TLV	Signature (2B)	

3B Fixed Header

9B Body

..Compare to 20/40B fixed IPv4/v6 header

[1] http://www.sigfox.com/en/#!/

e.g. 4GB ICN Content Object

E=1	Ver (3b)	Msg Type (4b)
Hop Limit (1B)		
Length (1B) = 0x00		
Extended Header TLV		
Optional Length TLV = 6B		
Name TLV		
Content TLV		
~4GB Payload		
Security TLV		

3B Fixed Header

+ 10 B ESH

Large 4GB MTU ICN Payload

Variable Payload length Type can allow GB/TB size Payload feasibility

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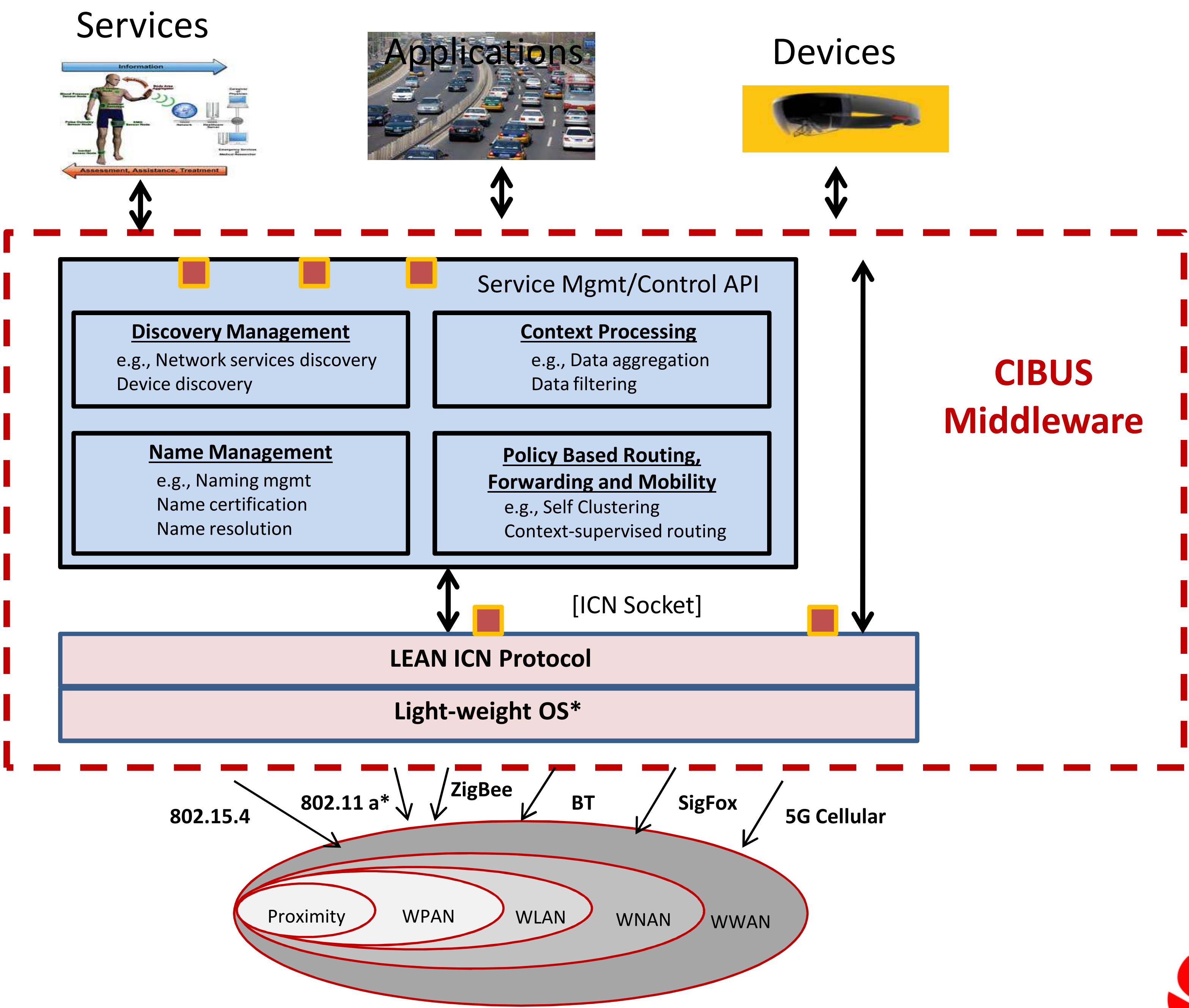
Common Information-Centric BUS (CIBUS) for IoT



Lean ICN stack with Middleware for Embedded Systems.

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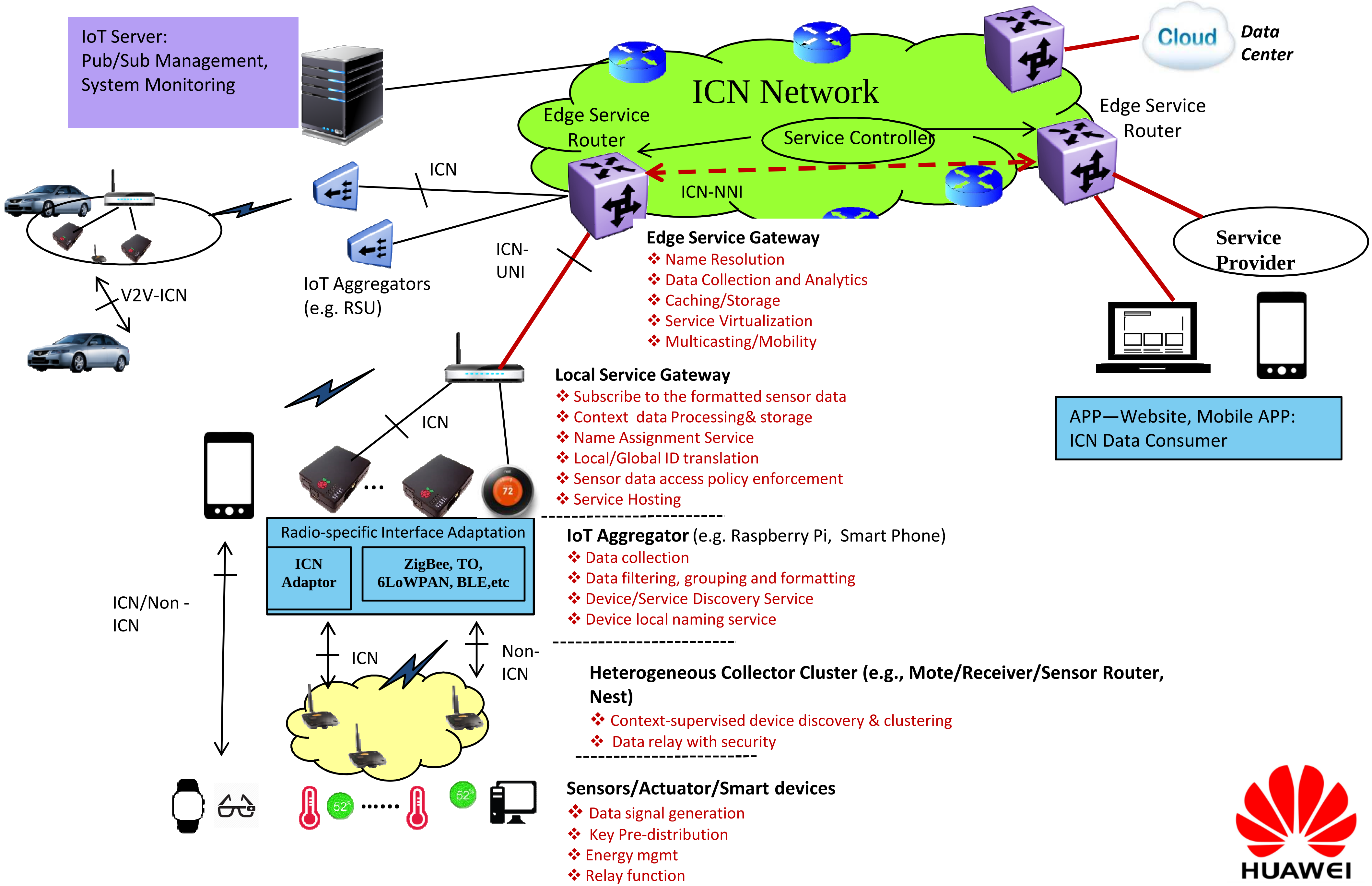
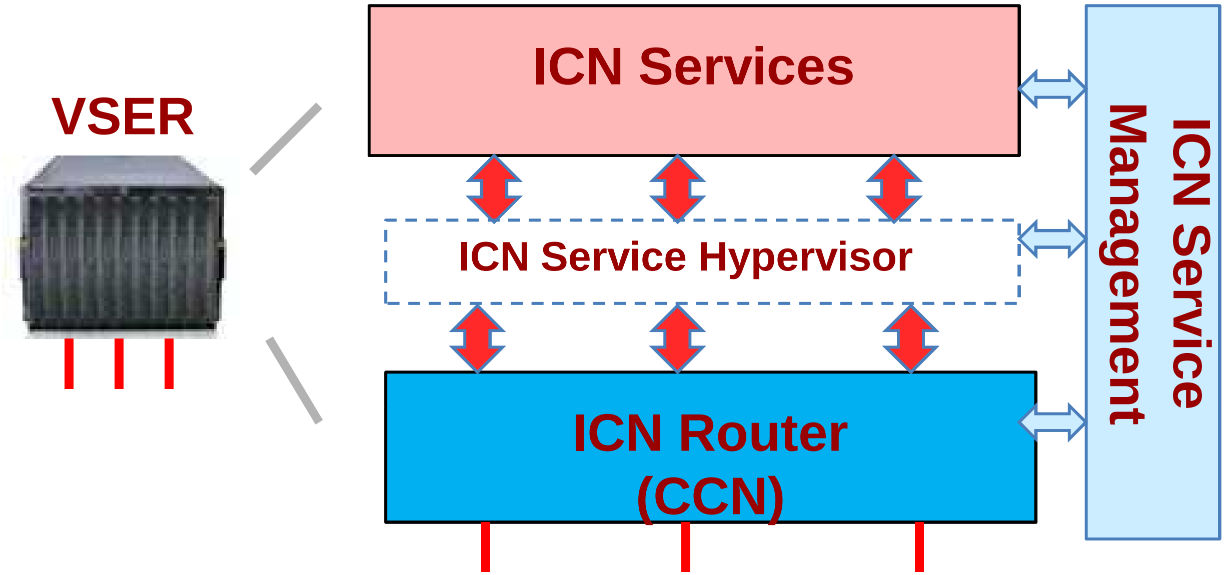
ICN-IoT Middleware Architecture: Distribution of Functions

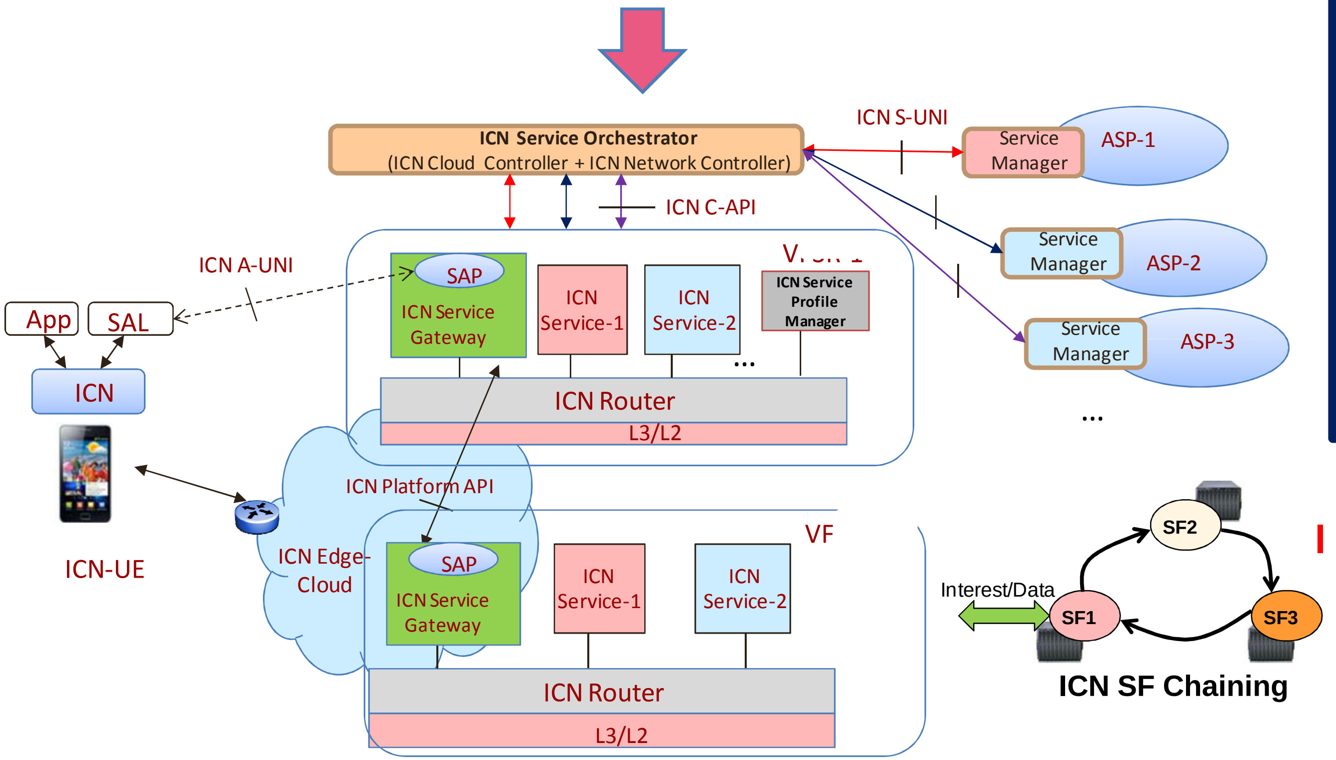
(IRTF/ICNRG draft, 08/2015, “draft-zhang-icn-iot-architecture-00”)



Virtual Service Edge Router Platform (VSER) and ICN-IoT Prototyping

VSER: Virtual Service Edge Router



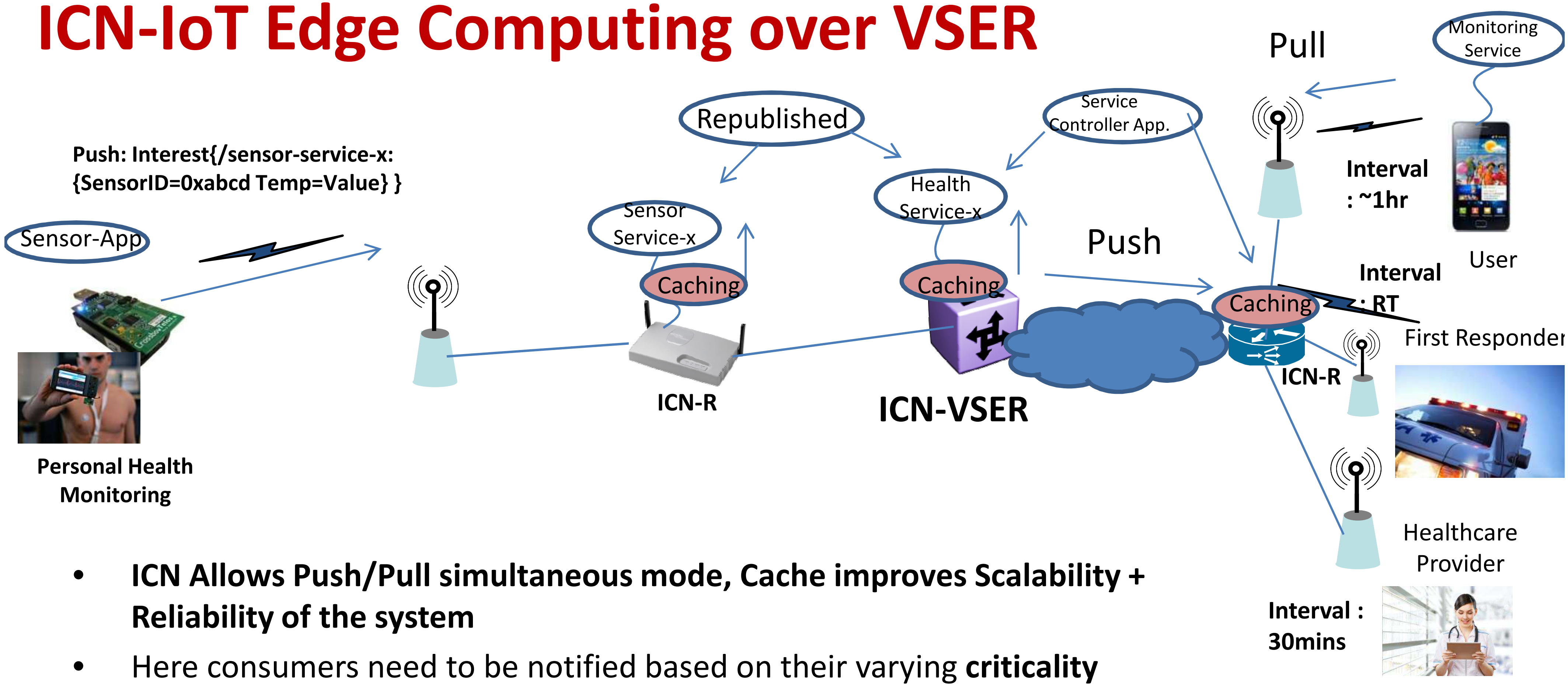


VSER Platform Highlights

- ICN Service Edge Virtualization
- ICN *Service Function* Life Cycle Orchestration and Management (by OpenStack and FloodLight.)
- Service Function Chaining
- Service Discovery, Service Contextualization.
- PULL/PUSH, MP-to-MP communication
- Unified control functions interworking with SDN/NFV
- “White box” Platform
- IP/ICN Dual-mode forwarding
- Optimized software stack including Multi-threaded CCNx.

[1] Asit Chakraborti et al, “ **A Scalable Conferencing framework over ICN Based VSER Platform**”, ICN, Sigcomm, 2015
[2] Ravi Ravindran et al, “**Towards Software Defined ICN Based Edge Cloud Services**” IEEE, CloudNet, 2013
[3] P. Talebifard, R. Ravindran et al, “**An Information Centric Networking Approach Towards Contextualized Edge Service** “, IEEE, CCNC, 2015

ICN-IoT Edge Computing over VSER



- **ICN Allows Push/Pull simultaneous mode, Cache improves Scalability + Reliability of the system**
- Here consumers need to be notified based on their varying **criticality**
  - E.g. User/First-Responder/Healthcare Provider
- **Less critical consumers** can rely on cache while **more critical consumers** rely on notification.
- Notifications lost cannot be reproduced, cache helps from this perspective too.
- Increases the Scalability + Reliability of the IoT system.
- There are challenges, on how to learn names of dynamic content [1], and save overhead of updates when notifications are at different intervals.

[1] Jerome Francois et al, "**CCN Traffic Optimization for IoT**". https://hal.inria.fr/hal-00922728

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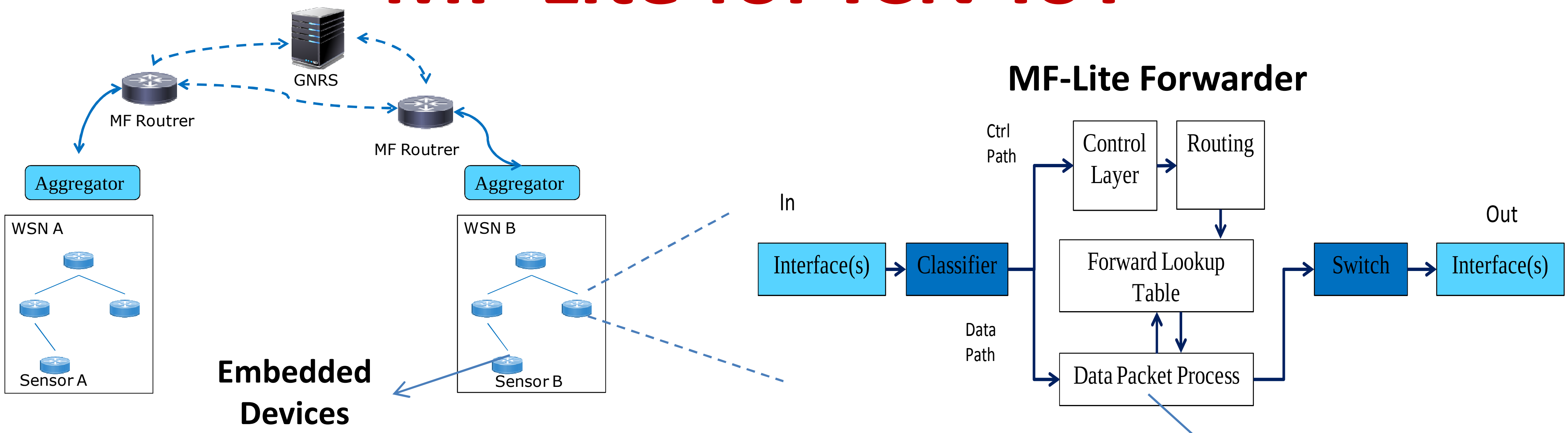
MF-Lite for ICN-IoT



0 1 2 3 4 Octet

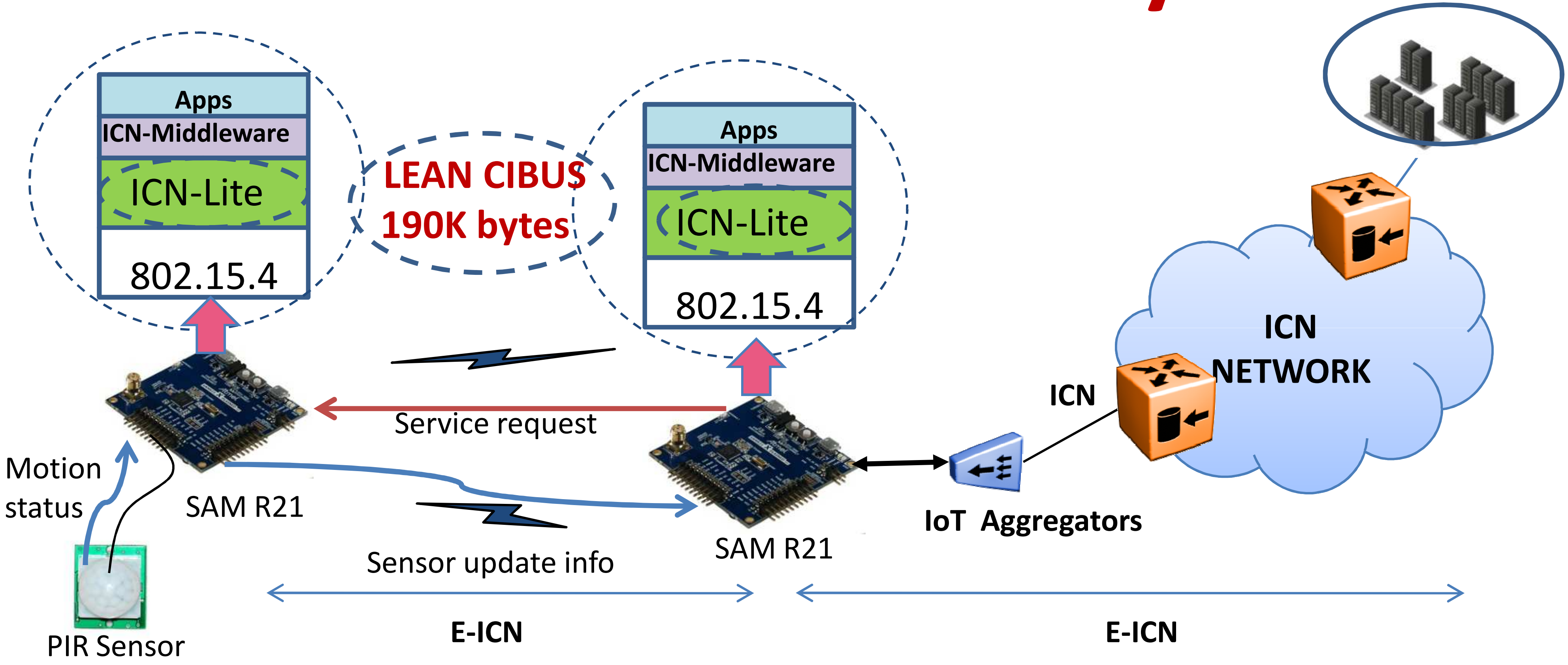
Version (4bits)	Pkt Type (4bits)	Service Type (4 bits)	Protocol (4 bits)	TTL	Reserved
Source ID				Destination ID	
. Payload .					

- Support basic Service Type Processing
- Push/Pull

- **Objective here to realize some of the ICN-IoT middleware on embedded devices over 802.15.4 Radio**
- **Naming and Secure Content Push/Multi-Hop/PUSH/PULL**
- **Over SAM-R21 Boards as Relay as well as Sensor Nodes**

[1] Li, S., Zhang, Y., Raychaudhuri, D., Ravindran, R., Zheng, Q., Wang, GQ., and L. Dong, **"IoT Middleware over Information-Centric Network", Global Communications Conference (GLOBECOM) ICN Workshop, 2015.**

ICN-IoT over Embedded Systems



- Zero-conf Device-to-Device interaction over ICN using Elastic ICN implementation
- Build considering End-to-End E-ICN, No Protocol Gateways
- Supports Application-centric Naming , Routing, Multicasting, and In-Network Computing
- Platform: RIOT OS and CCN-lite
- **Boards: Sam R21 with 256K bytes ROM, 32K bytes RAM ~ current footprint for CCN-lite+ App ~ 29KB**
- Sensor: PIR motion detect sensor

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Conclusions

- A fully programmable 5G infrastructure could allow operation of ICN-IoT technology
- ICN offers a natural service-centric platform to enable end-to-end Service Virtualization.
- IoT applications are information-centric, hence benefits from several ICN features.
- 5G SE-RAN proposal integrates traditional smart devices with CIBUS enabling connectivity and self-organization to all the IoT devices.
- Collaborative research with Winlab on ICN-IoT middleware with focus on architecture design, research and system prototyping.

Thank You..and

5G and Beyond

Sonia Heemstra de Groot

Netwerkdag
SURF
3 November 2016

CWTe
Centre for Wireless Technology Eindhoven

TU/e Technische Universiteit **Eindhoven** University of Technology

Where innovation starts

WHERE ARE WE NOW?

Where are we now? Mobile networks- 4G

LTE, LTE Advanced

- **Faster broadband**
- **Higher capacity**
  - OFDM/SC-FDMA
  - Flexible support for wider channels (up to 100 MHz)
  - More antennas (MIMO)
  - Channel aggregation for higher data rates
- **Peak data rate**
  - 300+ Mbps/75 Mbps (LTE)
  - 1Gbps/500Mbps (LTE advanced)
- **Low latencies**
- **Simplified core network (All IP)**

Where are we now? WLAN - WiFi

- IEEE802.11/a/b/g/n/ac
  - 2.4GHz and 5GHz
  - ac: MU-MIMO-OFDM
    up to 1.69 Gbps/stream (160 MHz, 8 antennas/AP, 2/STA)
- IEEE802.11ad
  - 60 GHz
  - Up to 6.75 Gbps/stream
- IEEE802.11p
  - Optimized for Car 2X communication - ITS
  - 5.9 GHz

Where are we now? Evolution towards IoT

- **Short range**

ZigBee

4.0 Bluetooth

- **Long range low power**

SIGFOX

LoRa

6LoWPAN
IPv6-based Low-power Wireless Personal Area Networks

2G 3G

IEEE802.11ah HaLow

Where would we like to go?

Broadband multimedia messaging

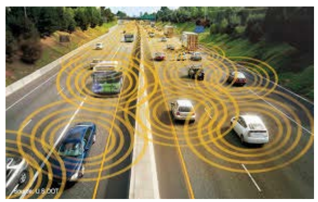
Extreme HD video steaming

Holographic watch

Haptic holography

Virtual teleportation

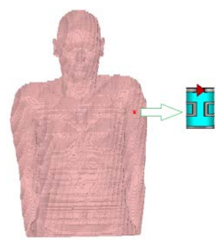
Connected vehicles



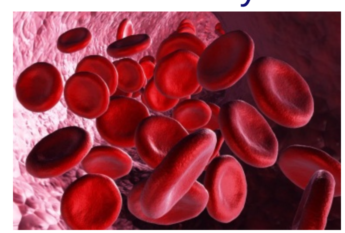
Autonomous driving

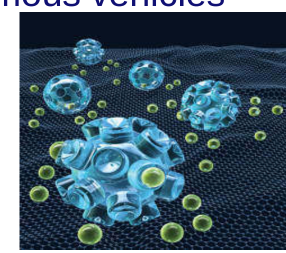
Fully autonomous vehicles

Internet of everything

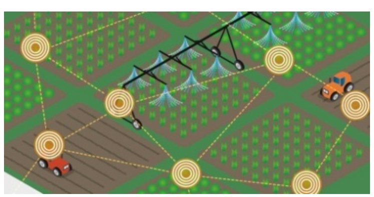


Implantable antenna





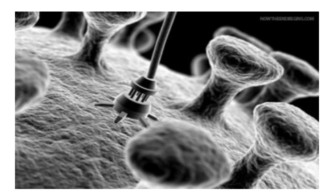
Nano IoT



Smart farming

Implantable wearables

In body networks



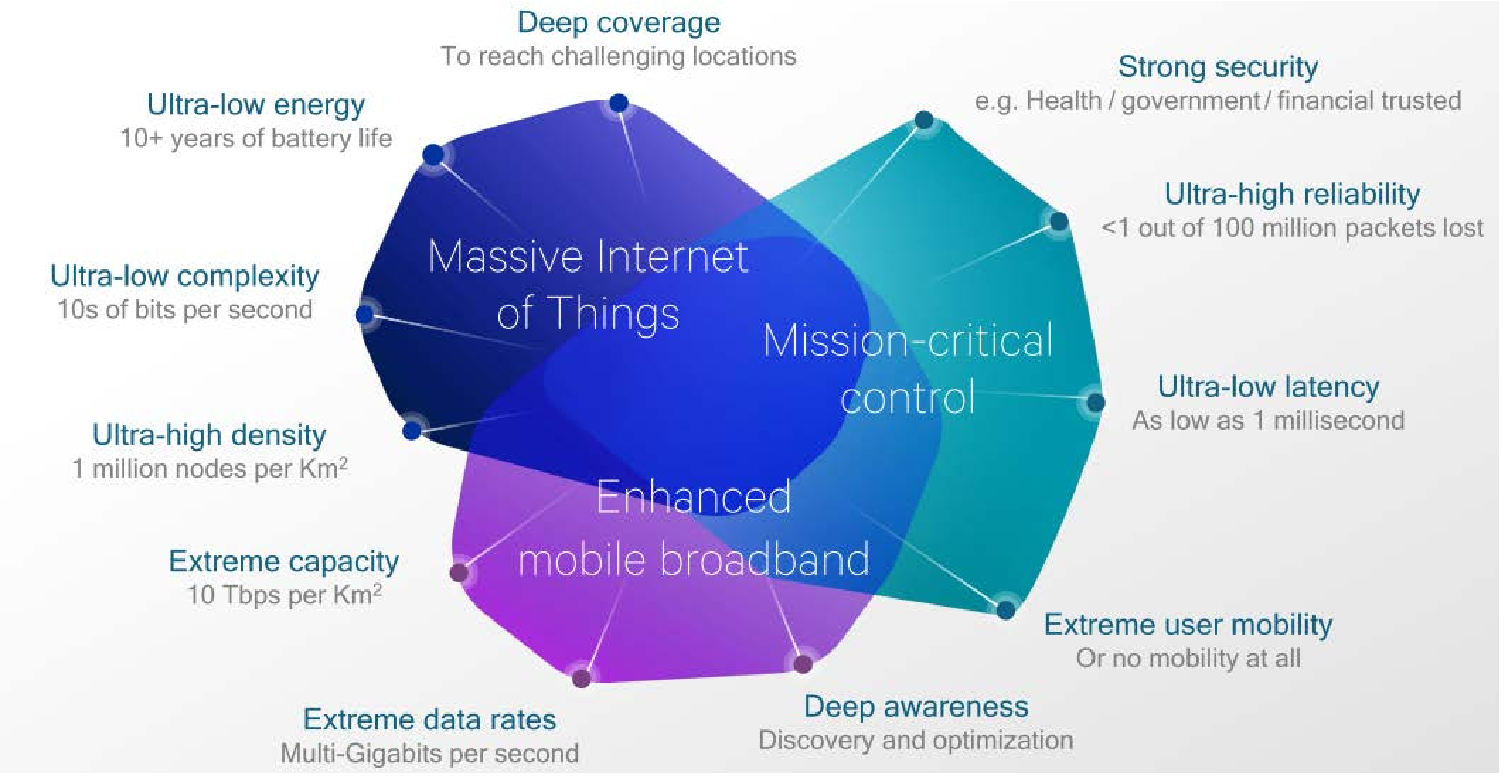
Nano swarms

2016 2020 2024 2028 2030 2034

Next Step 5G

REQUIREMENTS

Extreme variation of requirements*



*From Qualcomm Technologies, Inc. February 2016

Unified spectrum

Sub GHz: Long range massive IoT

1GHz to 6GHz: Wider bandwidth for enhanced mobile BB and mission critical

Above 6GHz. mmwave: Extreme bandwidth, shorter range extreme broadband

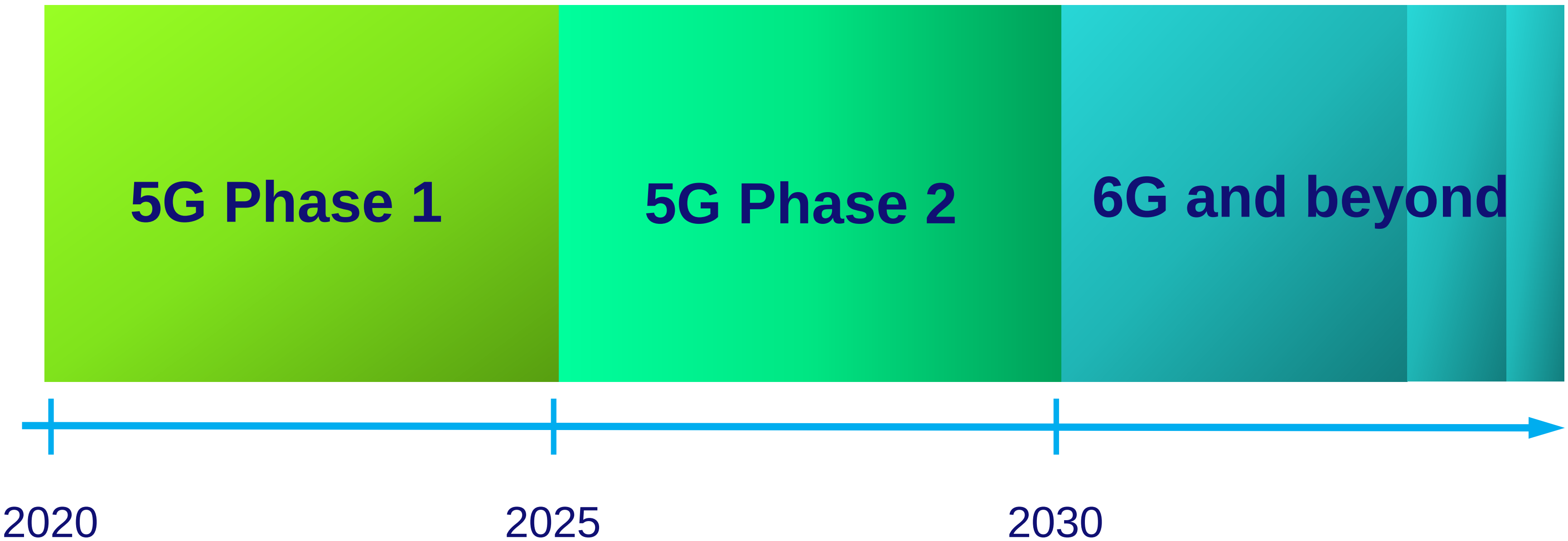
5G CHALLENGES

Multiple challenges

- Exploding traffic volume
- Random and diverse traffic
- Explosive growth of connected devices
- Control plane load (IoT, IoE)
- Low cost
- Energy efficiency

5G
TECHNOLOGIES

Timeline for 5G



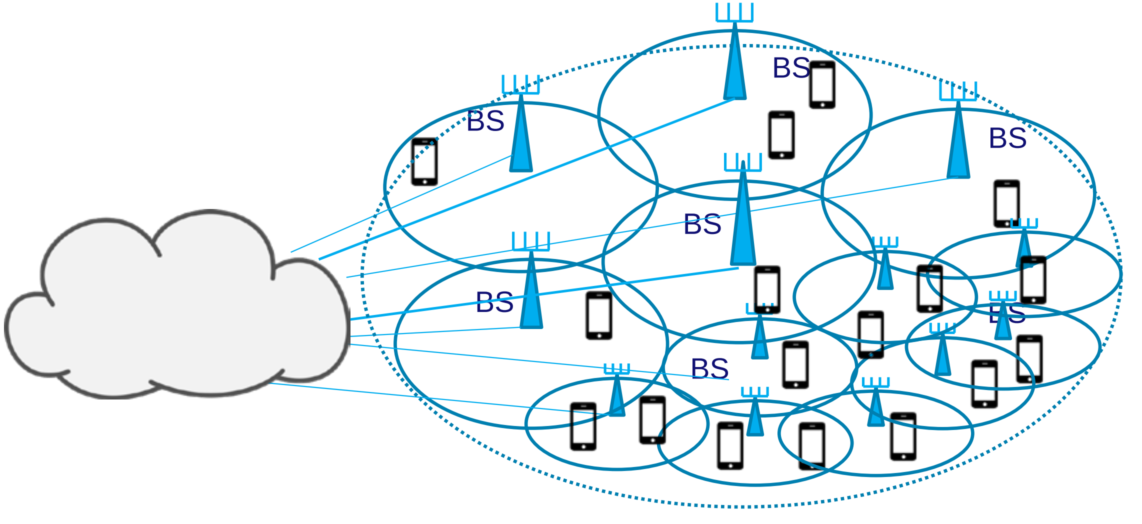
Using spectrum allocated in WRC 2015 below 6GHz

Adding spectrum allocated in WRC 2019 above 6GHz

New generation

5G Key technological components - Network

- **Ultra Dense Heterogeneous Networks**
  - **Macro cells combined with**
  - **Small cells: picocells and femtocells**
    increase of spectral efficiency, improved coverage, reduction of transmit power



5G Key technological components - Network

- **Ultra Dense Heterogeneous Networks**
  - **Macro cells combined with**
  - **Small cells: picocells and femtocells**
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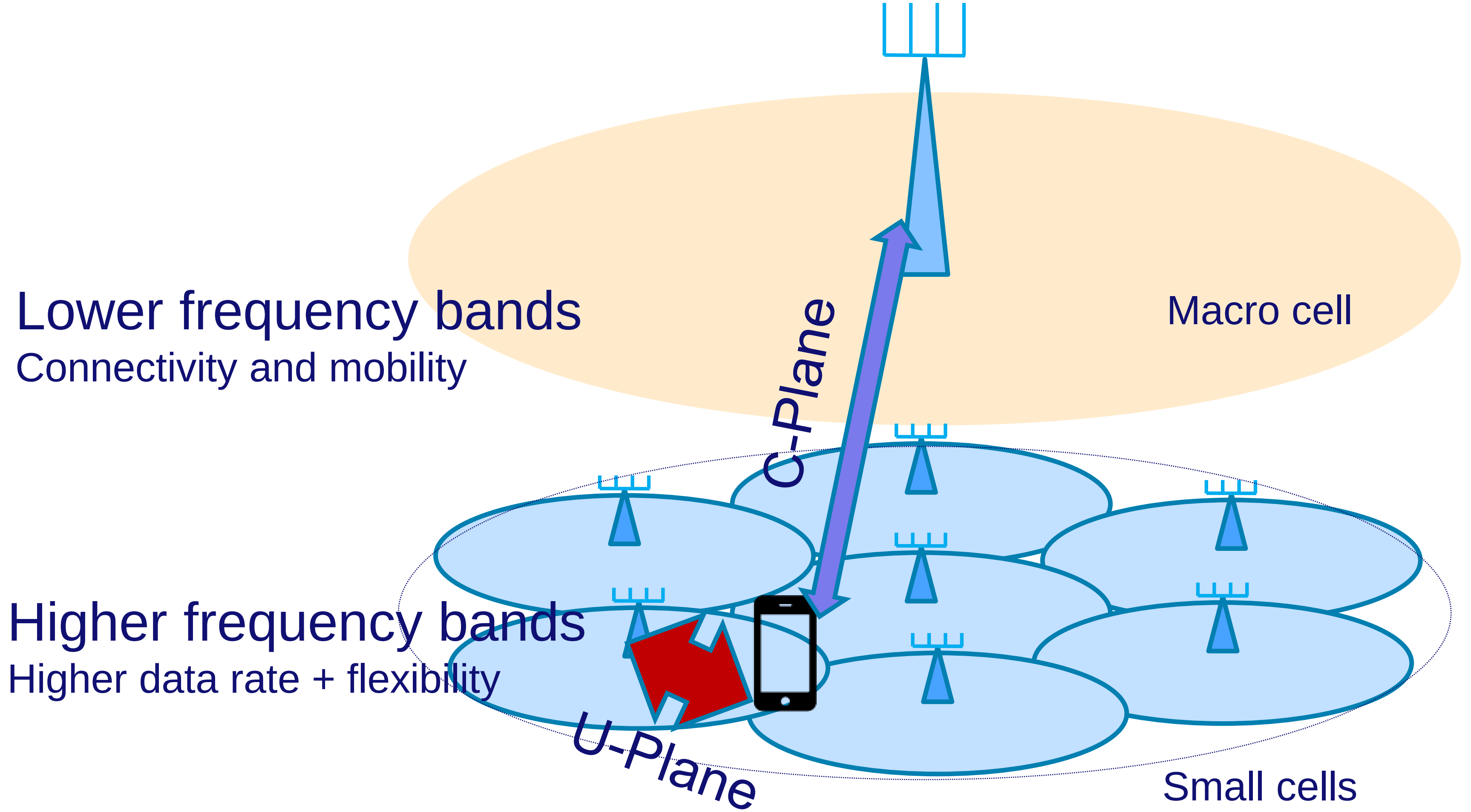
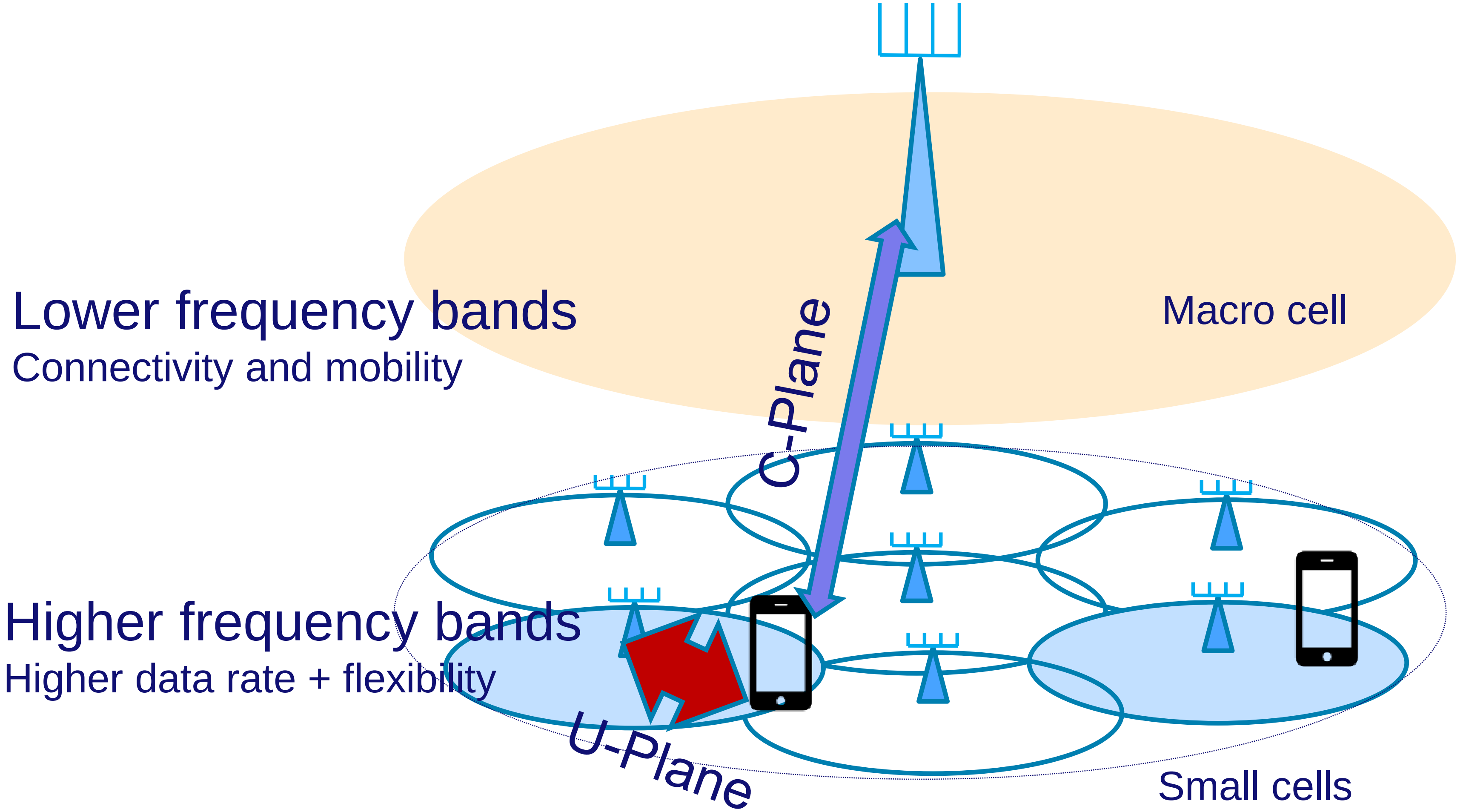
  - **Separation of data and control planes**

    connectivity with two BS: macro for control, small cell for transport

C/U Plane split



C/U Plane split



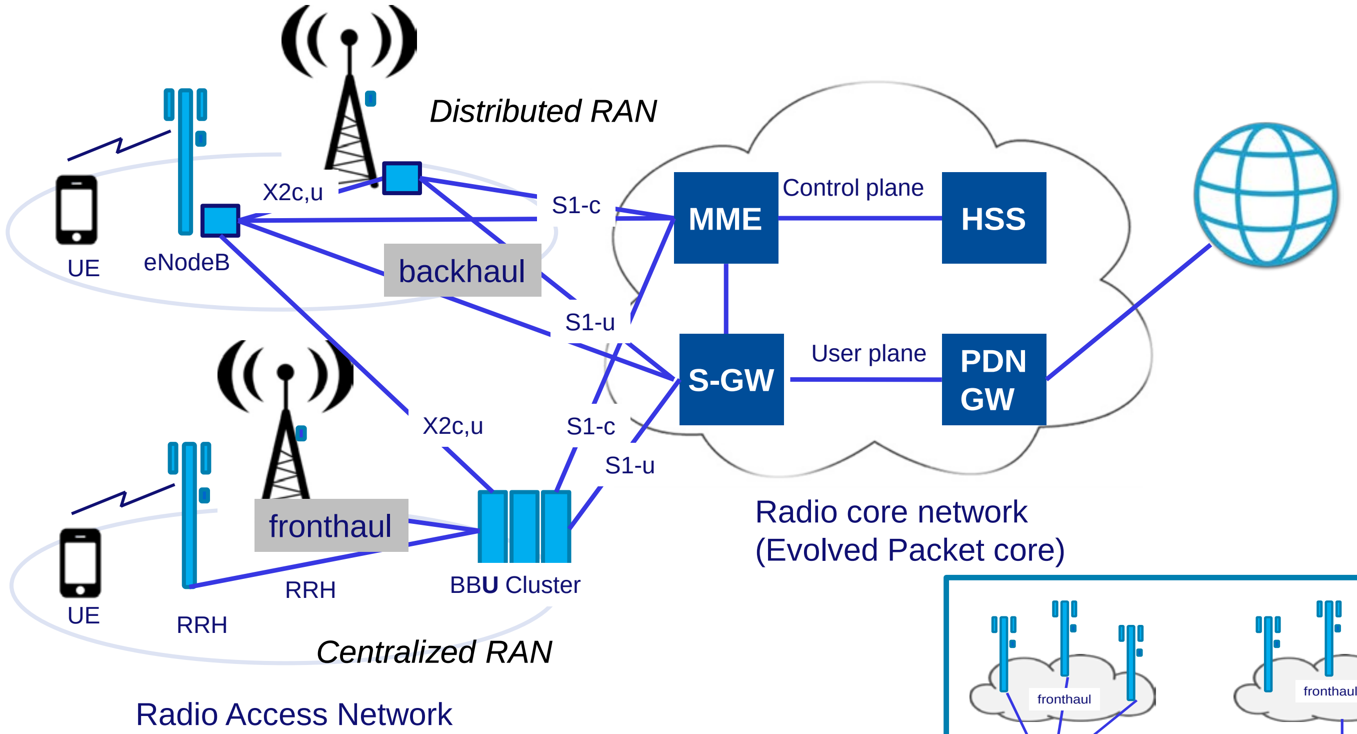
Energy efficiency: Switching cells on/off according to the demand

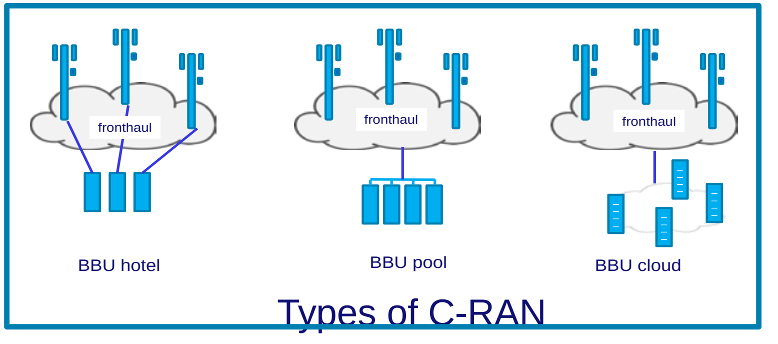
5G Key technological components - Network

- **Ultra Dense Heterogeneous Networks**
  - **Macro cells combined with**
  - **Small cells: picocells and femtocells**
    increase of spectral efficiency, improved coverage, reduction of transmit power
  - **Separation of data and control planes**
    connectivity with two BS: macro for control, small cell for transport
  - **Multiple radio-access technologies**
  - **Device-to-device communication (D2D)**

5G Key technological components - Network

- **Cloud or Centralized RAN (C-RAN)**



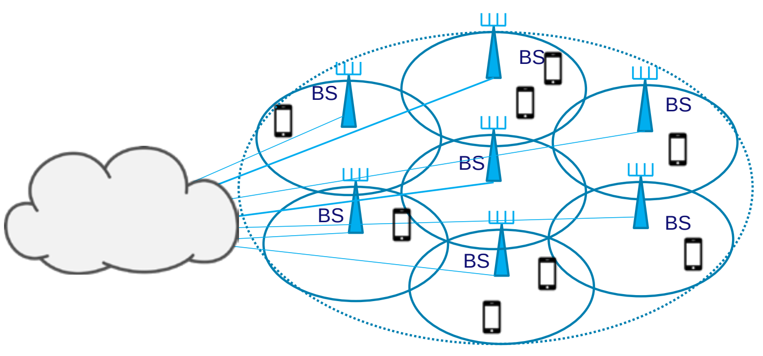


5G Key technological components - Network

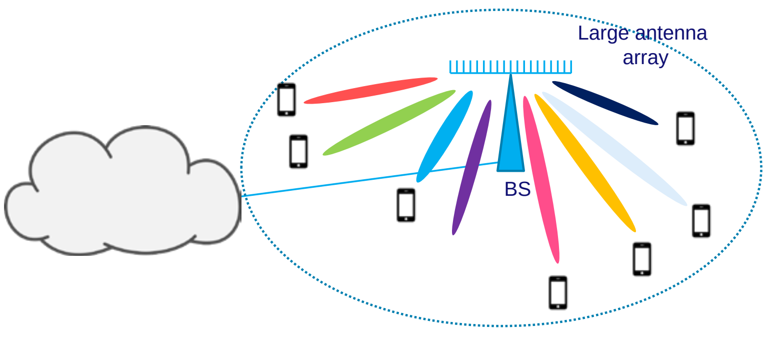
- **Cloud or Centralized RAN (C-RAN)**
  - OPEX and CAPEX benefits
  - Simplified implementation of advanced radio transmission techniques that require inter-cell cooperation
  - Sharing of processing capacity among multiple antenna sites
- **Software Defined (Cellular) Networks**
  - Virtualization - NFV
  - Directly programmable architecture

5G Key technological components - Radio

- **Massive MIMO**
  - Extension to traditional MIMO utilizing a very large number of antennas and spatial multiplexing
  - Several spatial streams
  - Dramatic increase of capacity and improved radiated energy-efficiency



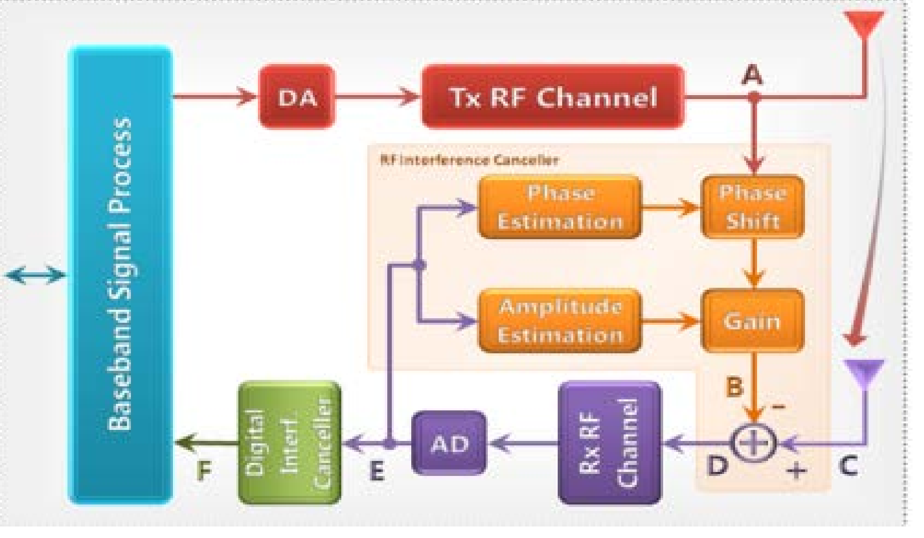
Small cells



Massive MIMO

5G Key technological components - Radio

- **Full duplex**
  - Simultaneous receptions and transmission
  - Doubling spectral efficiency
  - Self-interference cancellation – 120 dB for outdoor

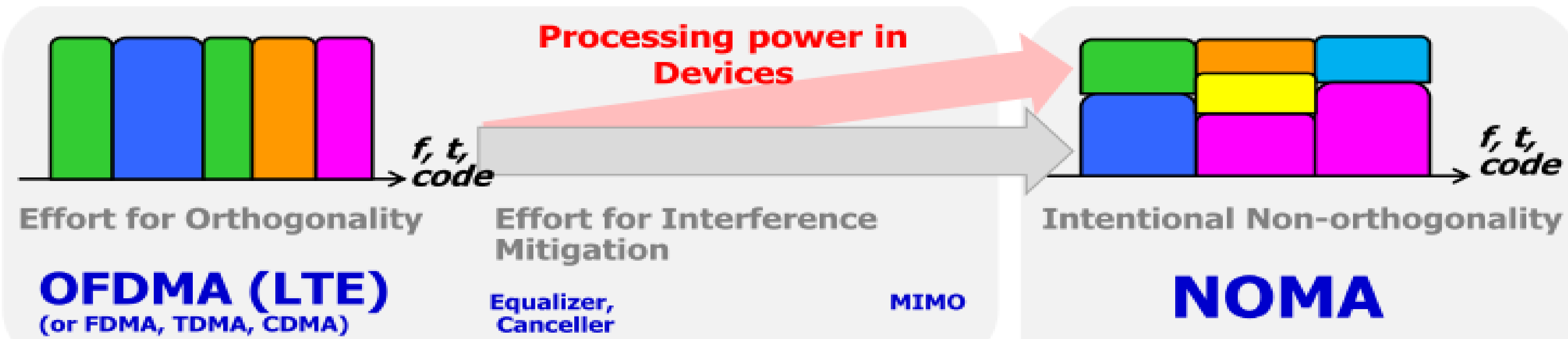


Self-interference cancellation Procedure[1]

[1]*Source: 5G White paper Future Mobile Communication Forum*

5G Key technological components - Radio

- **Alternative Multiple Access**
  - Non-Orthogonal Multiple Access (NOMA)

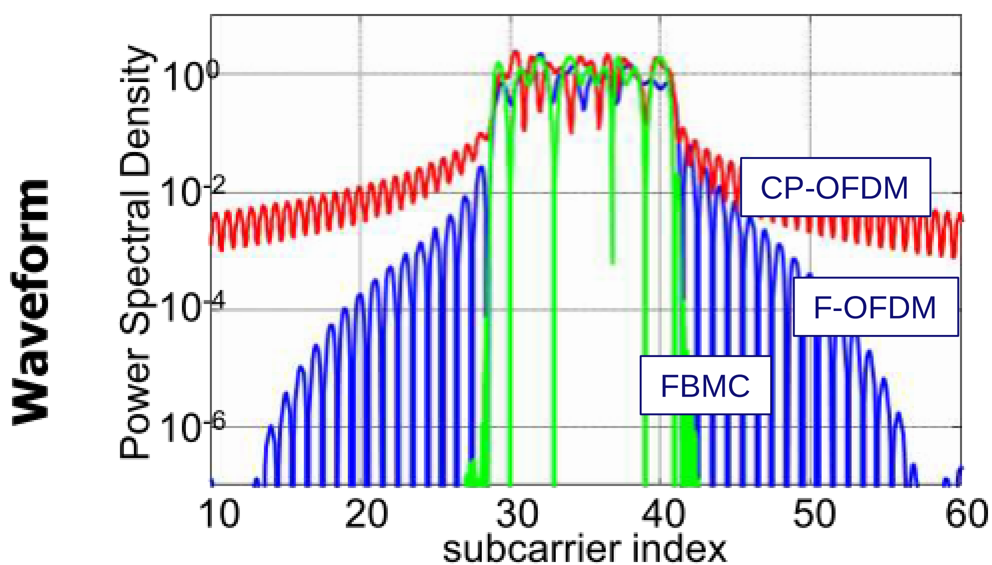


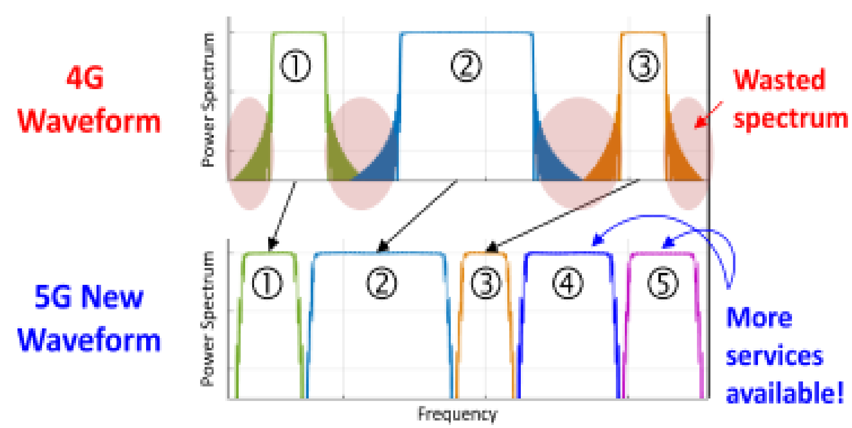
  - Increase spectral efficiency
  - Combined with SIC at the receiver
  - Increase of complexity

Source: T. Nakemura, Towards 5G Deployment in 2020 and Beyond

5G Key technological components -Radio

- **Alternative waveforms**
  - Flexible waveforms to support both broadband and IoT
  - New waveforms to significantly reduce the out-of-band leakage
    - Filter bank multicarrier and filtered OFDM as alternative to CP-OFDM





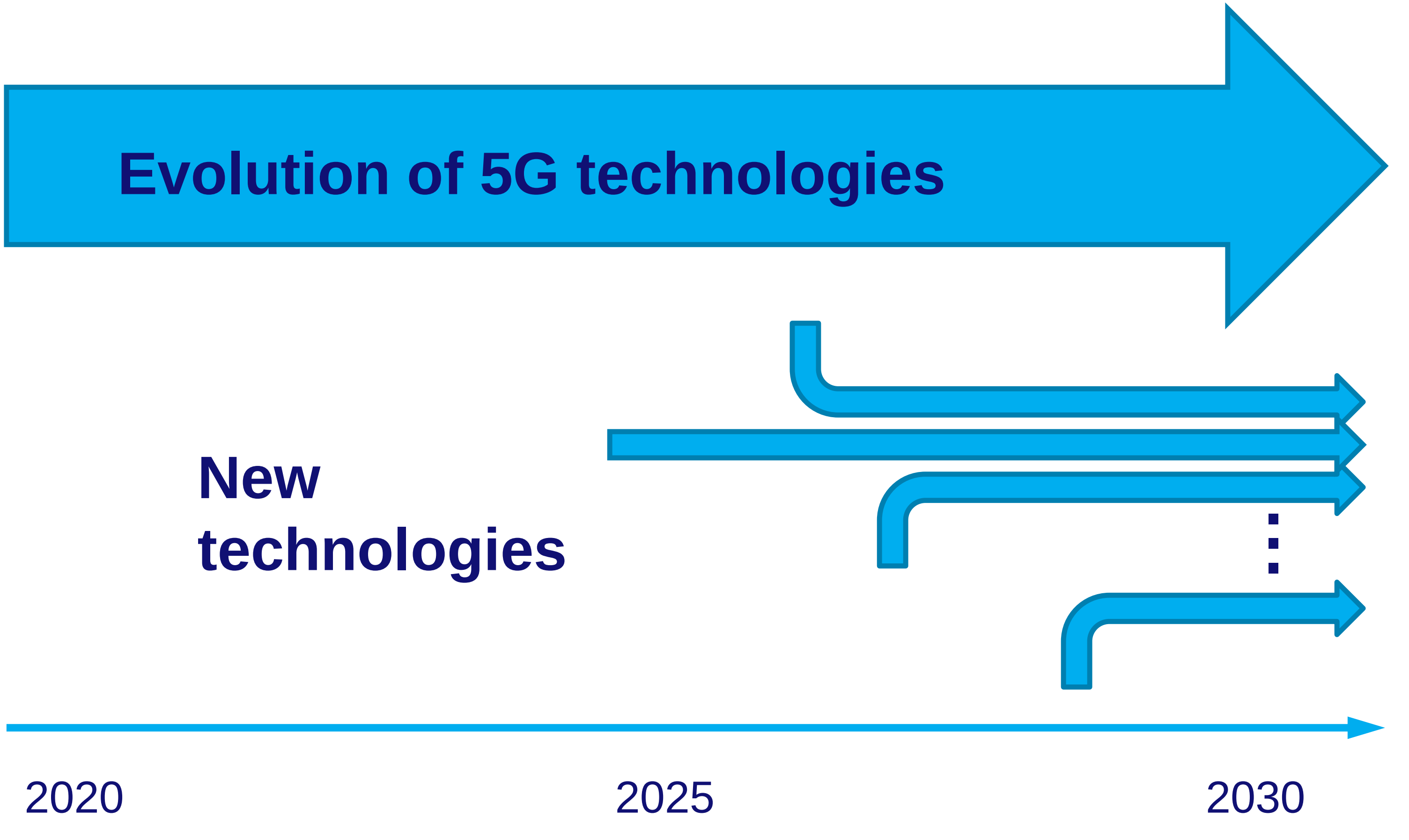
Source: T. Nakemura, Towards 5G Deployment in 2020 and Beyond

Advanced 5G and Beyond
TECHNOLOGIES

5G + Requirements

- Perception of “Infinite” capacity
  - Ultra-high data rates
  - Massive scalability to millions of devices
- Coverage
  - Ubiquitous consistent user experience in time and location
- Convenience
  - Extreme low latency (interactive services, tactile internet, remote surgery)
  - Long battery life/ ultra-low energy consumption

Wireless Research for Beyond 5G

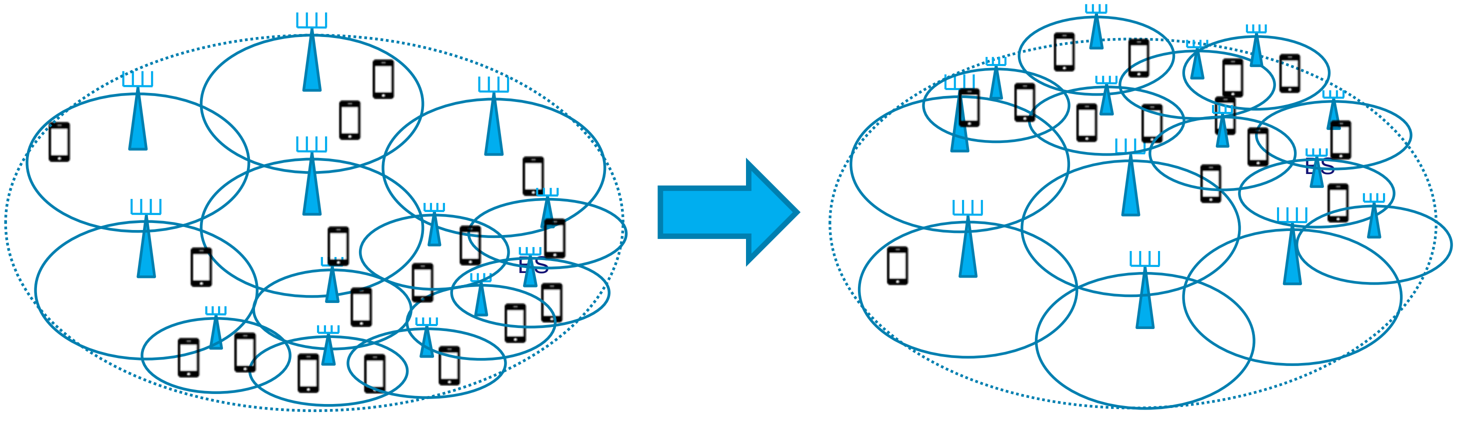


Wireless Research for 5G+ (1)

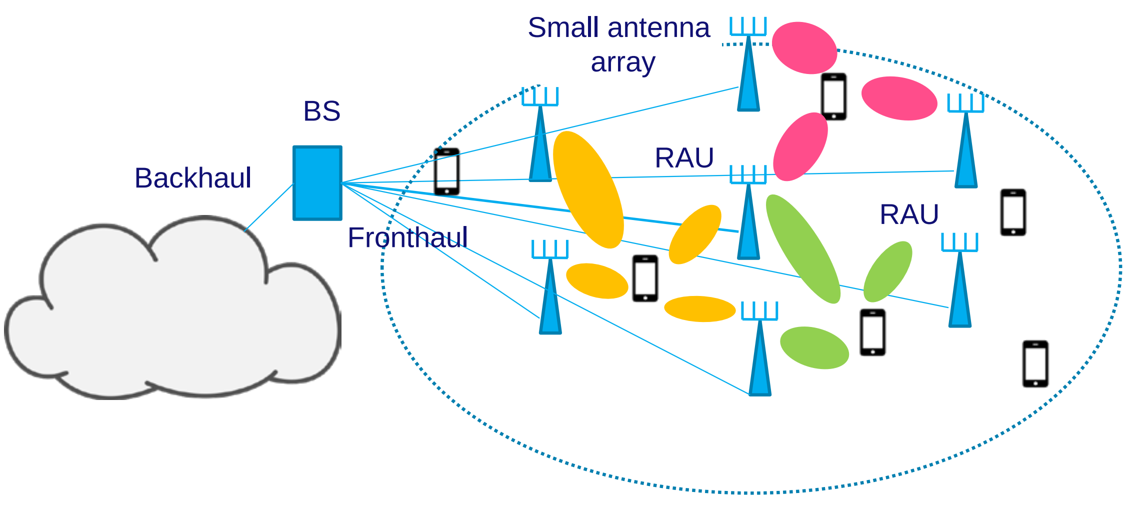
- **Evolutionary techniques**
  - **Increase spectral and energy efficiency**
  - **Flexible allocation of capacity**
  - **Advanced radio coordination techniques, e.g., distributed massive MIMO**

5G+: Flexible allocation of capacity

- Radio network dynamic reconfiguration
- Adaptive density of active antennas
- Different network overlays for different traffic classes
- Moving cells
- Wireless back/front haul



5G+: Distributed Massive MIMO

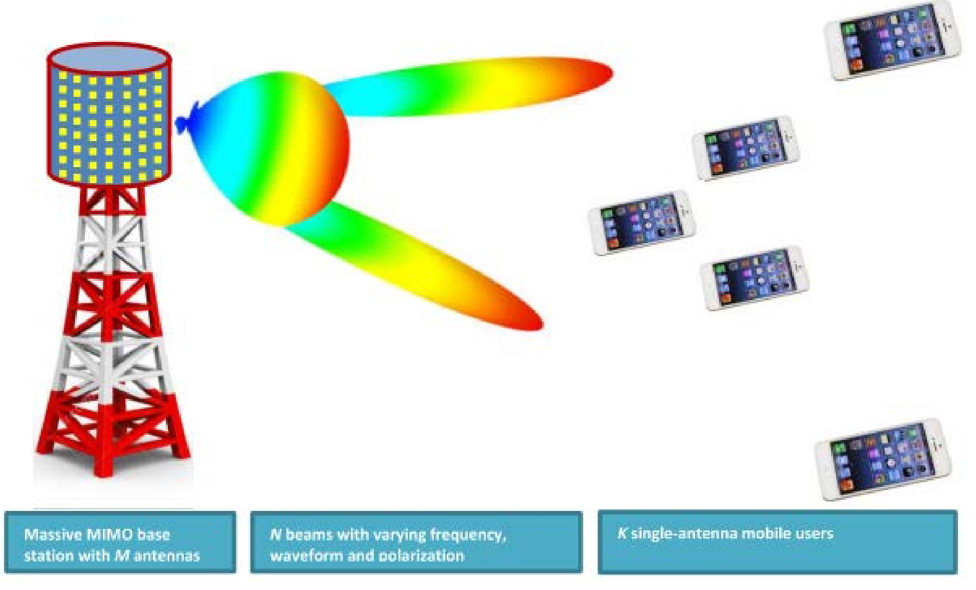


Wireless Research for 5G+ (2)

- **Use of higher spectral bands**
  - **30GHz – 300GHz**
  - **Communication and sensing**
    - Cellular radar
  - **Accurate positioning/localization**
  - **Optical wireless communication**
    - Visible light communication (VLC)
    - IR communication
  - **THz systems for sensing and communications**

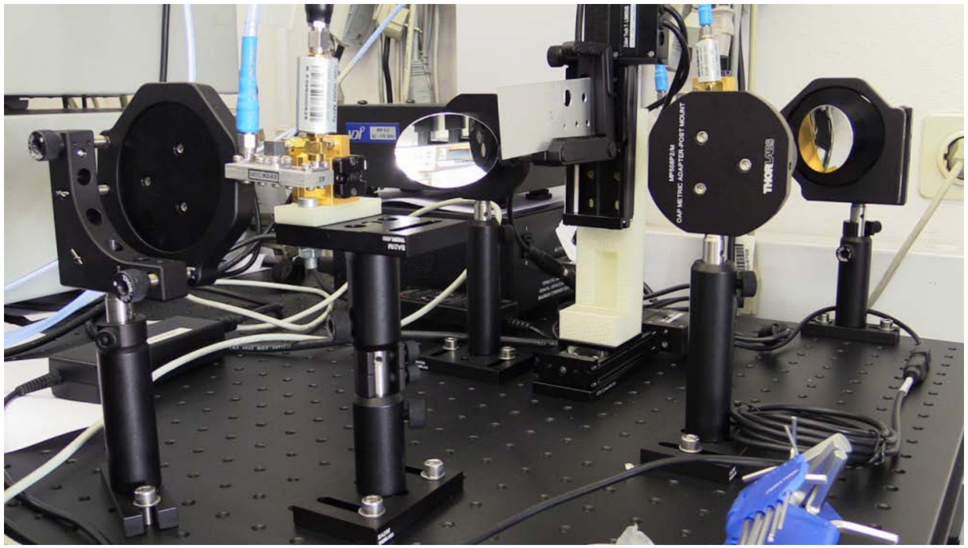
5G+ Antenna technology

- **H2020 SILIKA Project (Prof. B. Smolders)**
  - **mmwave multi-antenna systems for energy-efficient and low cost base stations for 5G wireless infrastructure**



Technologies for very high carrier frequencies

THz Systems



THz lab set up - Dr. M. Matters

presenteerde om het delen van transportmiddelen te faciliteren. Dat is wenselijk, omdat de gemiddelde bezettingsgraad van voertuigen de afgelopen twintig jaar met zo'n 10 % is afgenomen. Sharif Azadeh ontwierp een systeem waarin passagiers kunnen aangeven welke reis (waarheen en wanneer) zij willen maken en of zij

keuze verandert onder invloed van gezondheidsbeleid.'
De hoeveelheid data die je in modellen kunt stoppen lijkt schier oneindig, maar worden ze daar ook nauwkeuriger van? Volgens Chorus zijn eenvoudige modellen op hoofdlijnen vaak al 90 % nauwkeurig. Maar dat maakt die laatste 10 % niet minder interessant. TW
www.heart2016.org/

wege de logistiek en de windbelasting de grootste uitdaging. Het 55 m lange en 560.000 kg wegende val werd met twee drijvende bokken naar een locatie elders gebracht om daar gerenoveerd te worden. Ondertussen worden alle evenwichts- en bewegingskabels van het val vervangen. Eind dit jaar moeten alle werkzaamheden klaar zijn. TW
https://goo.gl/Ys3QGc

Boeken lezen met terahertzstraling

/// Eerste prototype
/// Negen pagina's diep

INDRA WAARDENBUG

ICT Onderzoekers van MIT zijn erin geslaagd om met een zelf ontwikkeld systeem door de eerste negen pagina's van een stapel papier te kijken. Het systeem maakt hiervoor gebruik van terahertzstraling, elektromagnetische straling met een golflengte tussen die van infrarood- en microgolfstraling. Met hun onderzoek, waarvan zij de eerste resultaten onlangs publiceerden in het blad Nature Communications, bouwen de wetenschappers voort op een technologie om door enveloppen heen te kijken zonder deze te openen.
Het prototype bestaat uit een terahertzcamera die ultrakorte pulsen uitzendt. Een ingebouwde sensor in de camera detecteert de reflectie van deze pulsen. Deze reflectie ontstaat doordat er zich minuscule luchtzakjes van 20 µm diep tussen de pagina's bevinden. Het verschil in refractie tussen lucht en papier zorgt voor de terugkaatsing van de terahertzstraling. Met behulp van een door de onderzoekers ontwikkeld algoritme blijkt de afstand tussen de verschillende bladzijden te bepalen. Hierbij kijkt het systeem naar de tijd tussen het uitzenden en het ontvangen van de straling. Daarnaast is het algoritme in staat om letters te identificeren, zelfs als de beelden vervormd zijn, of er delen van letters ontbreken.
Met het prototype konden de onderzoekers succesvol door de eerste twintig pagina's komen. Doordat het signaal deels wordt geabsorbeerd en deels heen en weer kaatst tussen de verschillende pagina's, is het signaal echter na negen pagina's zo zwak dat achtergrondruis het overstemt.
De onderzoekers willen nu de nauwkeurigheid van de detectoren verbeteren en de stralingsbron versterken. TW
https://goo.gl/rWDg7H

BARMAK HESHMAT

THz Imaging

Terahertz band: Next frontier for wireless communications

CWTe
Centre for Wireless Technology Eindhoven

TU/e Technische Universiteit Eindhoven University of Technology

Wireless Research for 5G+ (3)

- **Network intelligence/cognitive networks**
  - To deal with extreme large number of devices
  - To deal with high level of system complexity and uncertainties
  - Machine learning techniques
  - Self-organizing systems/autonomous, and self evolving systems

Network intelligence

- **Cognitive networks (Prof. A. Liotta)**
  - Automatic anomaly detection based on machine learning (running directly inside the sensor).
  - IoT playground with accurate monitoring, logging and analytics

Wireless Research for 5G+ (4)

- **Device miniaturization**
- **Extreme low power/ battery-less**
  - Cell powered devices and systems
- **Wearable electronics, flexible electronics, implantable electronics**

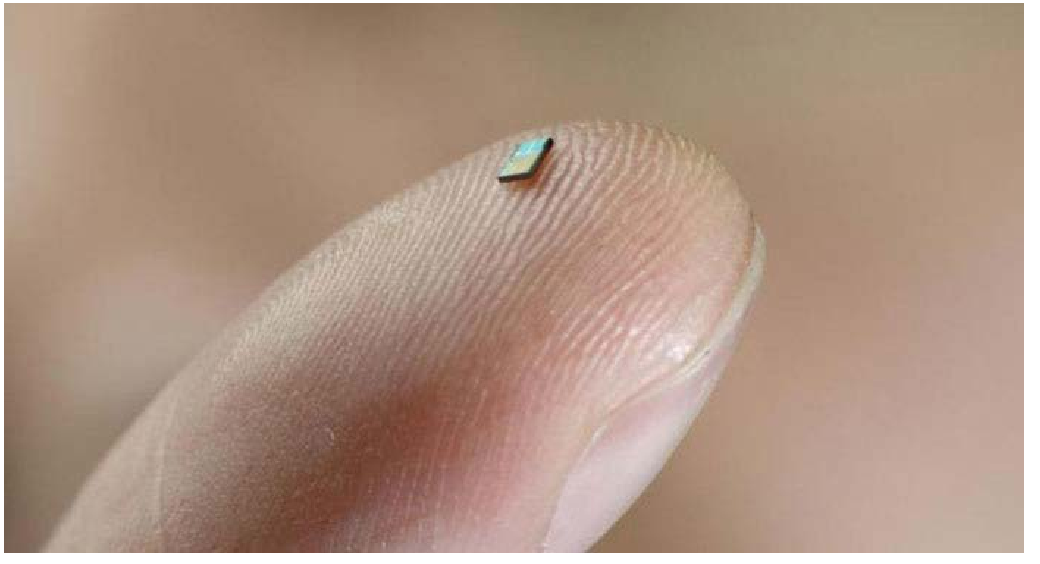
  In-body, on-body, from-body communication
- **Intelligence/sensing/communication embedded in the body and in the environment**

Extremely low-power devices

- **Pushing the limits of miniaturization and ultra-low power**

  CWTe –Premiss (Dr. Hao Gao)

  60GHz energy harvesting temperature sensor

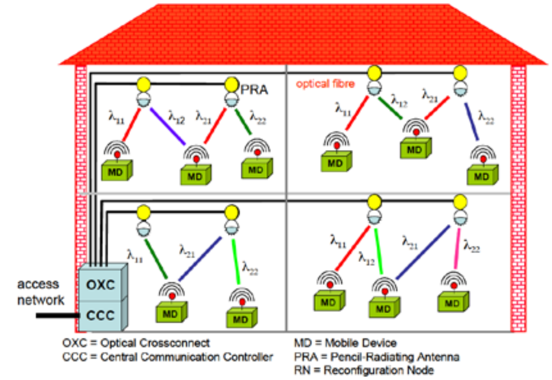


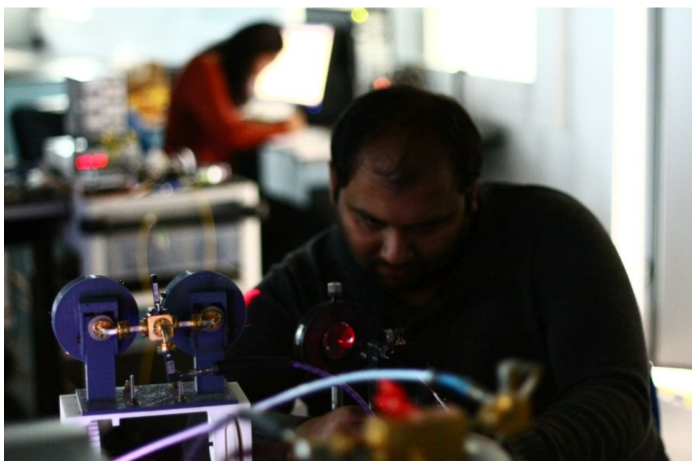
Wireless Research for 5G+ (5)

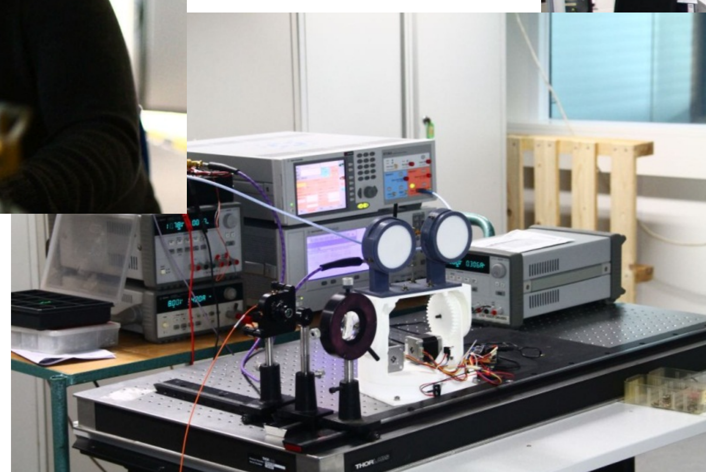
- **Close interworking wireless/optical communication**
  - Optical will be needed because of capacity and latency
  - Dynamic transport/routing for provision of capacity on demand
  - Optical-wireless communication

Optical technologies

- **Browse project – T. Koonen et al**
  - Multiple dynamically-steered free-space optical beams (downstream)
  - flexible mmwave radio communication techniques (upstream)







CONCLUSION

Final Remarks

- **5G is a big step to advance wireless systems**
  - **Extreme variation of requirements**
  - **Multiple challenges**
  - **First phase 2020-2025 lower frequencies**
  - **Second phase 2025-2030 mmwave**
- **Research beyond 5G**
  - **Evolution of 5G techniques**
  - **New technologies**
- **CWTe at TU/e working on 5G and beyond key research areas using interdisciplinary approach**

Thank you!

Feeling the (Pain of) Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, …

Richard Li, PhD

Chief Architect, Future Networks
Huawei USA
Renwei.Li@huawei.com

Expectation Always Grows with Success!

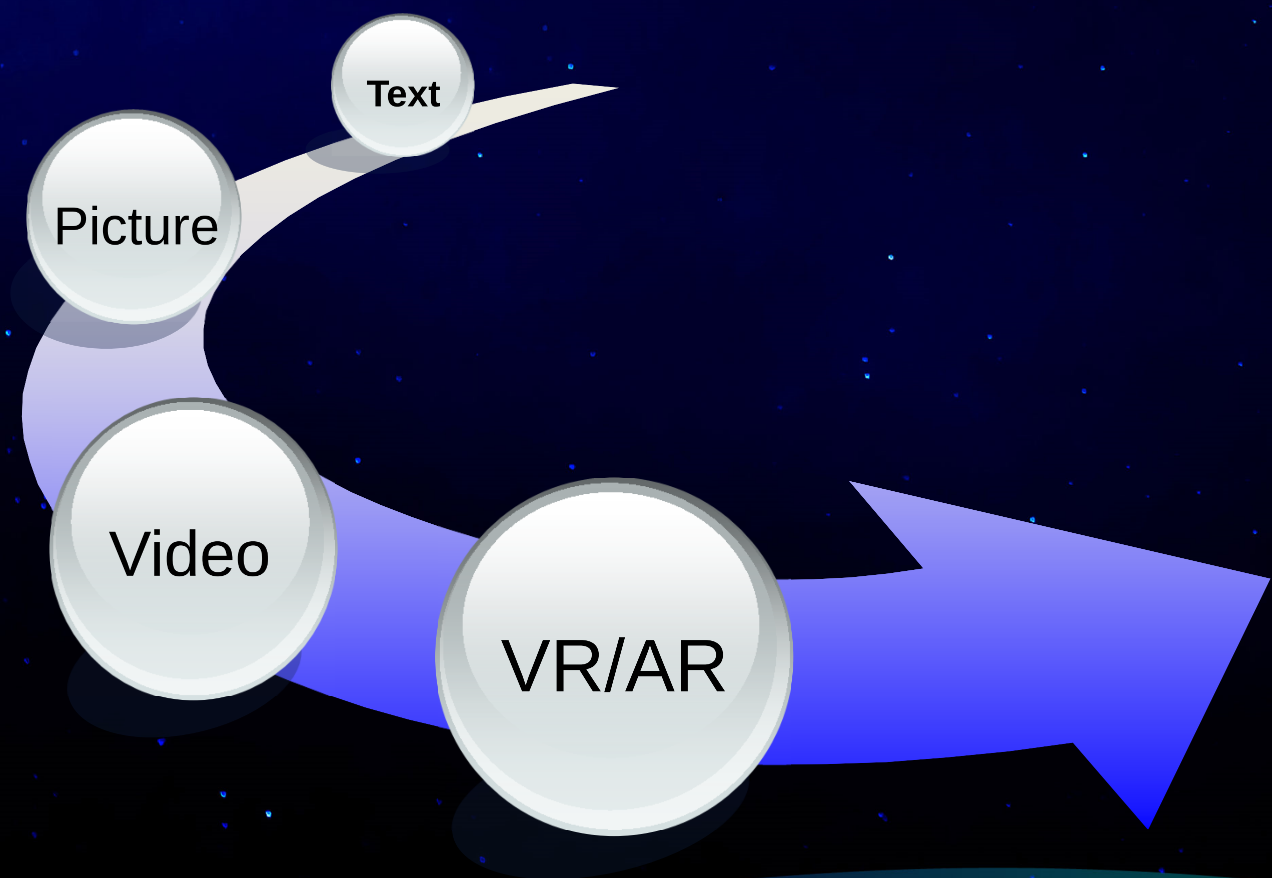
Expectation for runners:

- **When you run 100 meters in 10 seconds, you are expected to run it in 9.5 seconds**
- **When you reach 9.5 seconds, you are expected to run it in 9 seconds**
- **You will always be expected for something newer and harder!**

Expectation for the Internet

- **TCP/IP was initially expected to send/receive “lettergrams”**
- **When the Internet can successfully support “textual” applications, it is expected to support “image applications”**
- **When the internet can support “voice applications”, it is expected to support “video” applications**
- **When the internet can support video applications, it is expected to support “immersive experience” applications. But can it really support it?**

Evolution of Internet Applications



AR/VR: New Way to Live, to Play, to Work, to Share, to Design, to Experience, to Go beyond the Screen

Source: Modification of https://www.youtube.com/watch?v=aThCr0PsyuA

Can the Internet Support any New Applications?

New Requirements

- High Throughput (1-10Gbps)
- Low Latency (1ms)

Obstacles

Physics

❖ Light speed: 300km/ms

Protocols

❖ 40-year old design

Real Transport: 100km/ms

Economics

❖ CapEx
❖ OpEx

Emerging Technologies

mmW | 5G | IoT | V2X | ION | SDN | NFV | MEC

Panelists

- **Tommy Svensson:** Challenges and Opportunities with mm-wave Communications in 5G
- **Valerio Frascolla:** Mobile Edge Computing, a key building block for 5G networks
- **Eugen Borcoci*:*** Centralized SDN control in distributed IoT environment - is it possibly an efficient cooperation ?

Thank you

www.huawei.com

Panel on Communications on ICN & SPACOMM

Topic: Feeling the (Pain of) Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

SDN, NFV, MEC.. in IoT Environment?

Eugen Borcoci
University POLITEHNICA Bucharest
Electronics, Telecommunications and Information Technology Faculty (ETTI)
Eugen.Borcoci@elcom.pub.ro

NexComm Conference, 23-27 April, Venice

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

Facts:

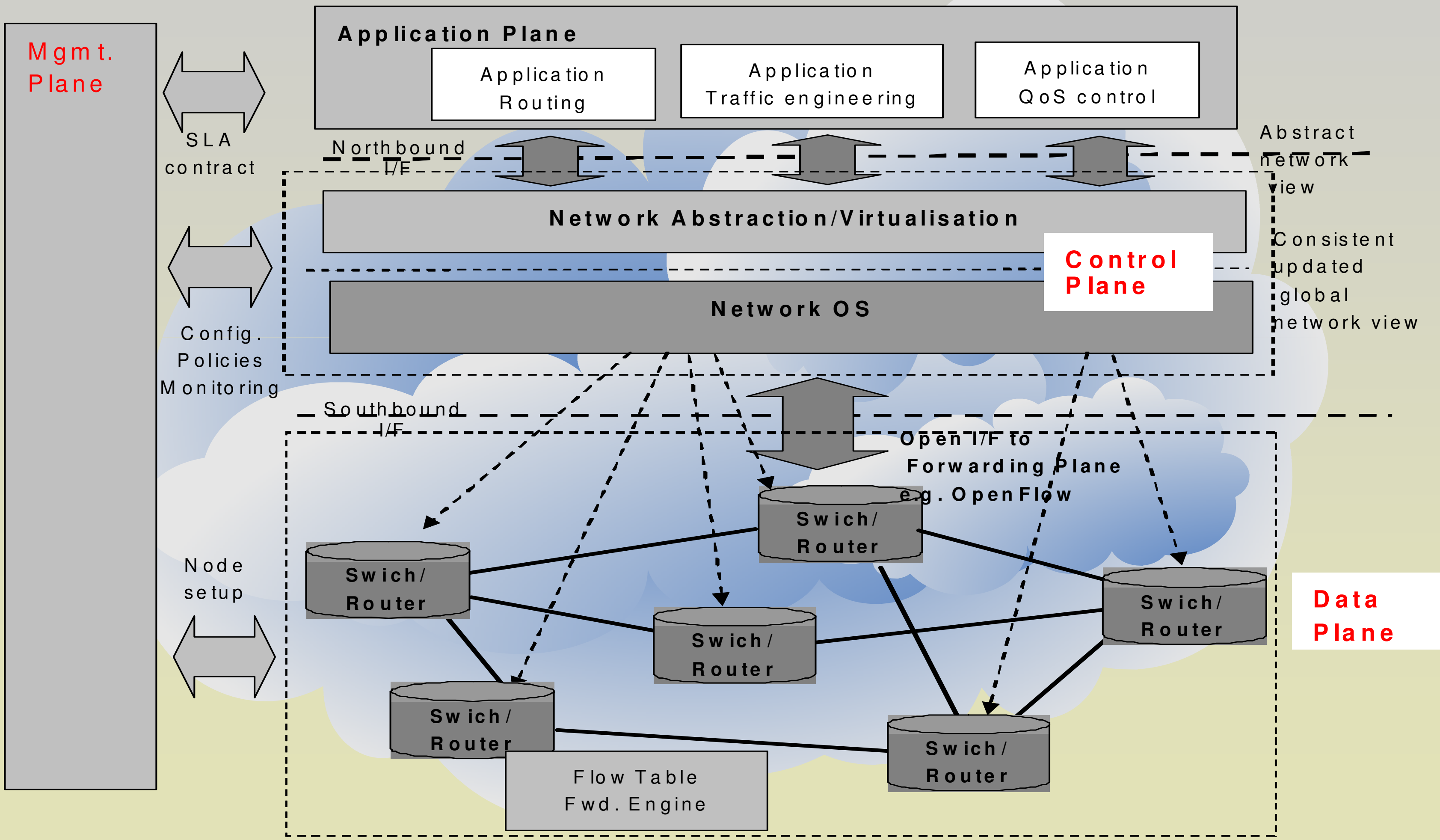
- **Internet and Telecom convergence → Integrated networks: Future Internet**
- **Novel services, applications and communication paradigms**
  - **Internet of Things (IoT) and Smart cities, M2M and Vehicular communications, Content/media oriented communications, Social networks,**
  - **Internet of Everything (IoE), etc.**
- **Novel, emergent technologies** are changing networks and services architectures :
  - ***Supporting technologies***
    - ***Cloud Computing***
    - ***Fog/Edge Computing /Mobile Edge Computing /Cloudlets***
    - ***Software Defined Networks (SDN)***
    - ***Network Function Virtualization (NFV)***
    - ***Advances in wireless technologies: 4G-LTE, LTE-A, WiFi, 5G***

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Software Defined Networking (SDN)**
  - **SDN – applicable in Clouds, WANs, IoT, vehicular, 5G**
- **SDN concepts and advantages:**
  - **Control Plane (CPl) and Data Plane (DPl) separation**
  - **centralized logical control and view** of the network
    - underlying network infrastructure is abstracted to applications
    - common APIs (northbound I/F)
  - Open I/Fs Southbound I/F CPl (controllers - DPl elements)
    - E.g. OpenFlow
  - **Network programmability**: by external applications including network management and control
  - **Independency of operators** w.r.t. network equipment vendors
  - Increased network reliability and security

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- ## SDN –architectural planes separation

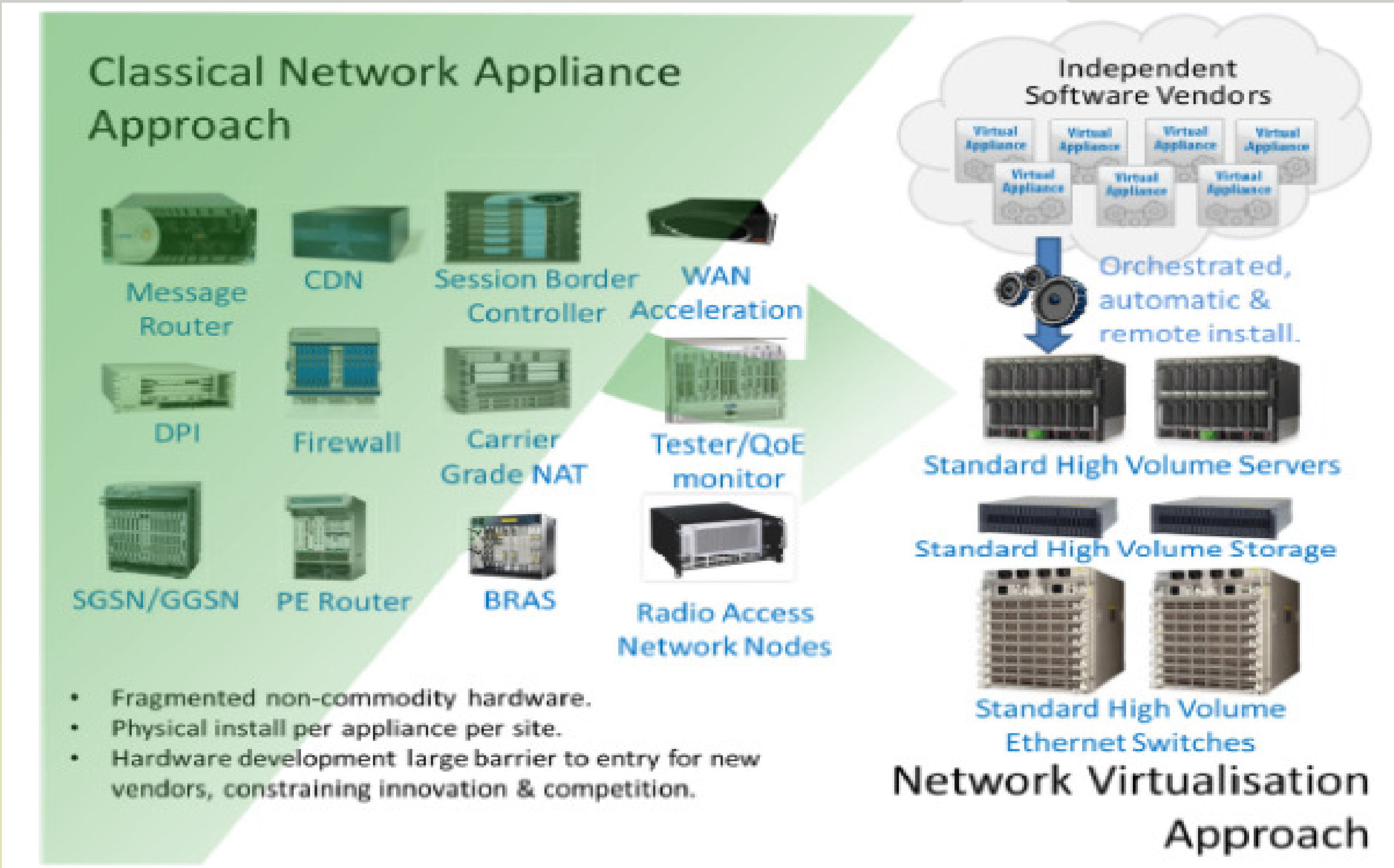


Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Network Function Virtualization (NFV)**
  - Using COTS computing HW to provide **Virtualized Network Functions (VNFs)**
    - Sharing of HW and reducing the number of different HW arch.
  - **High flexibility in assigning VNFs to HW**
    - better scalability (hope)
    - decouples functionality from location
    - enables time of day reuse
    - **Virtualization-** → flexibility and resource sharing
  - **Rapid service innovation** through SW -based service deployment
  - Higher **operational efficiencies**
  - **Reduced power consumption**
    - (VNF migration, instantiation, …)
  - **Standardized and open I/Fs**: between VNFs infrastructure and mgmt. entities

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

NFV vision (source : ETSI)



Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

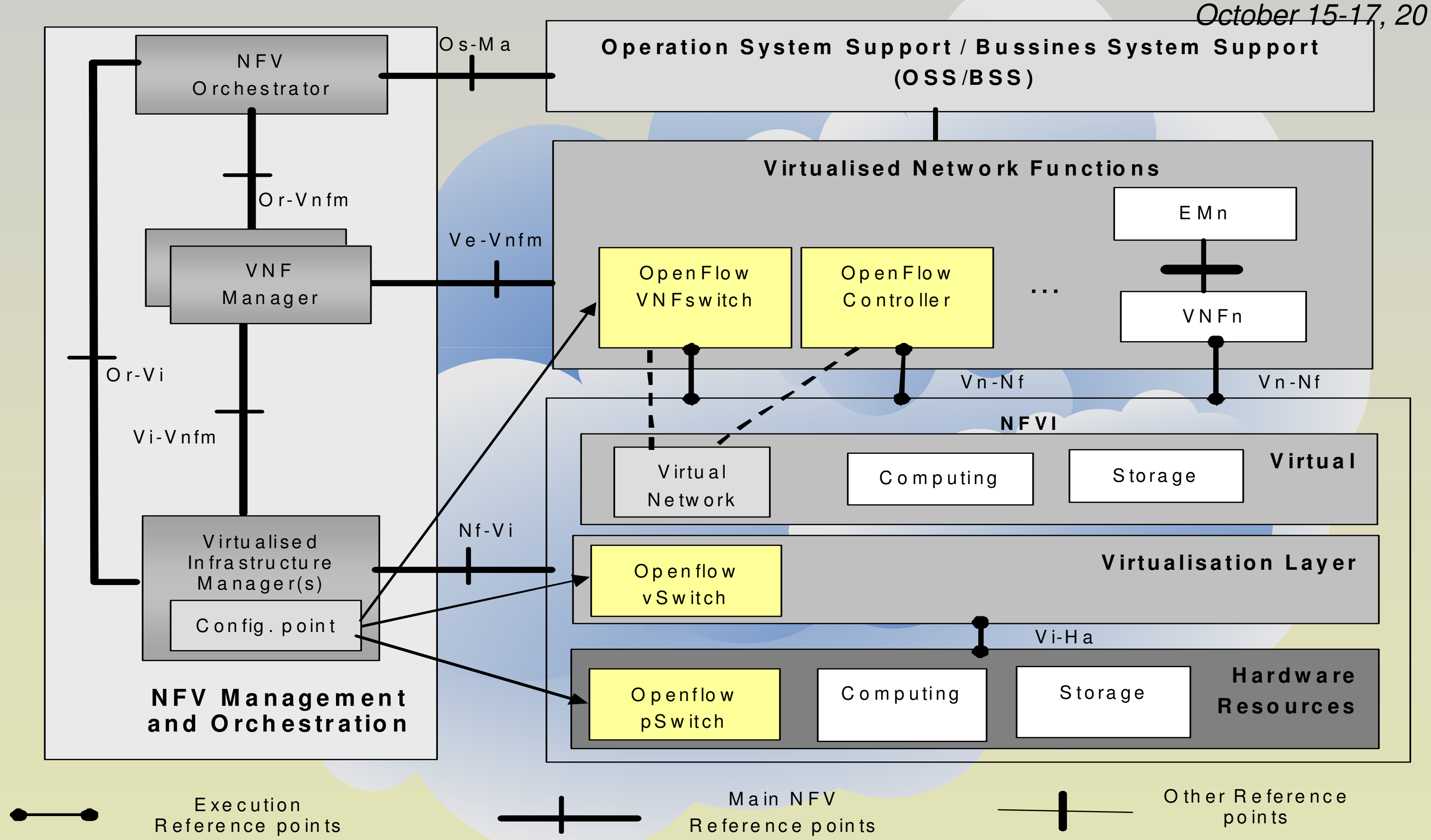
- **SDN and NFV –complementary (orthogonal?)**
  - SDN - **horizontal** separation in planes
  - NFV - **vertical** separation : HW/SW (applicable in both CPl and DPl)
  - They can be developed together
    - NFV provides functionalities
    - SDN provides “Tools”

- Cooperation
  - ETSI
  - ONF
  - IETF
  - ….

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

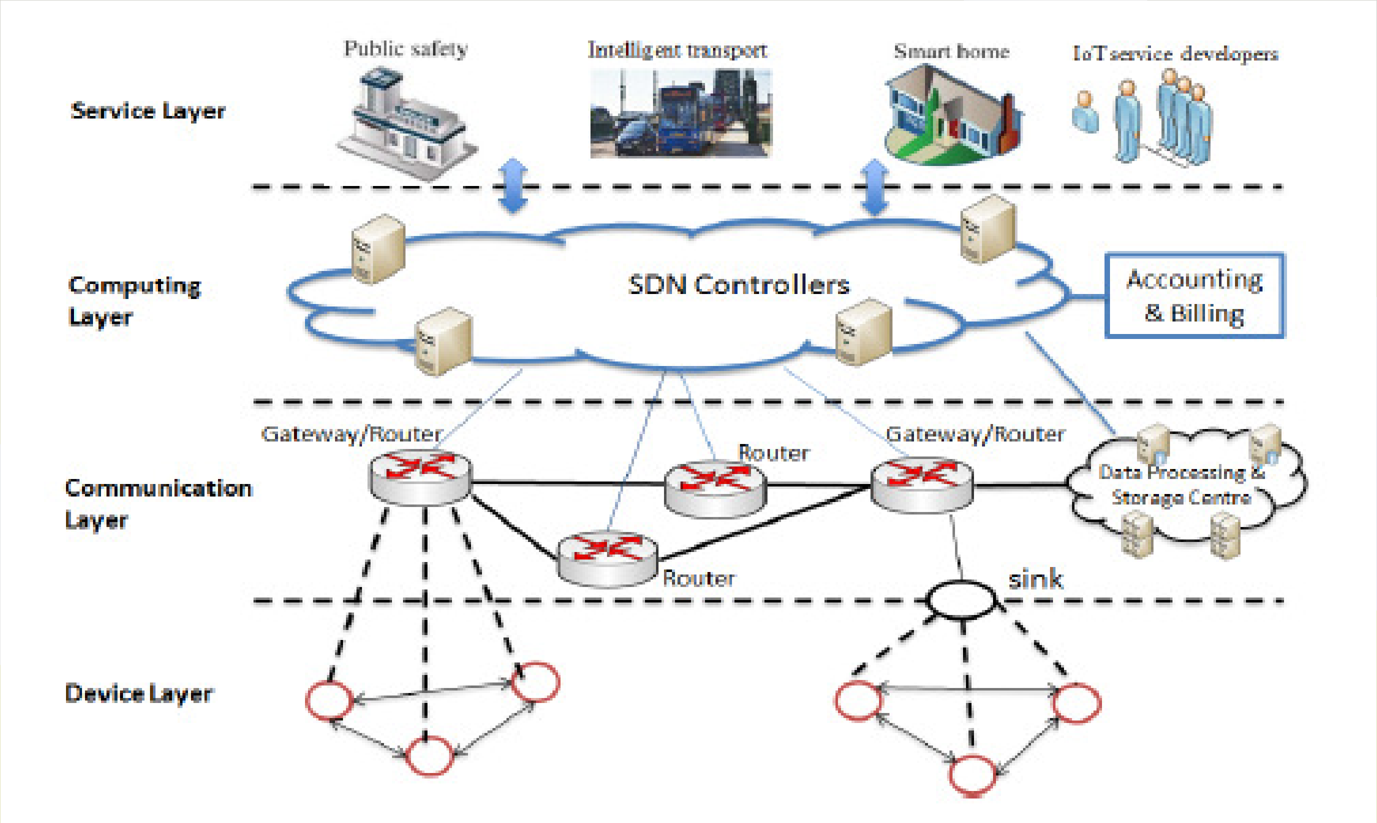
- **SDN and NFV –are complementary- example**

Source: "SDN and OpenFlow World Congress", Frankfurt, October 15-17, 2013



Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

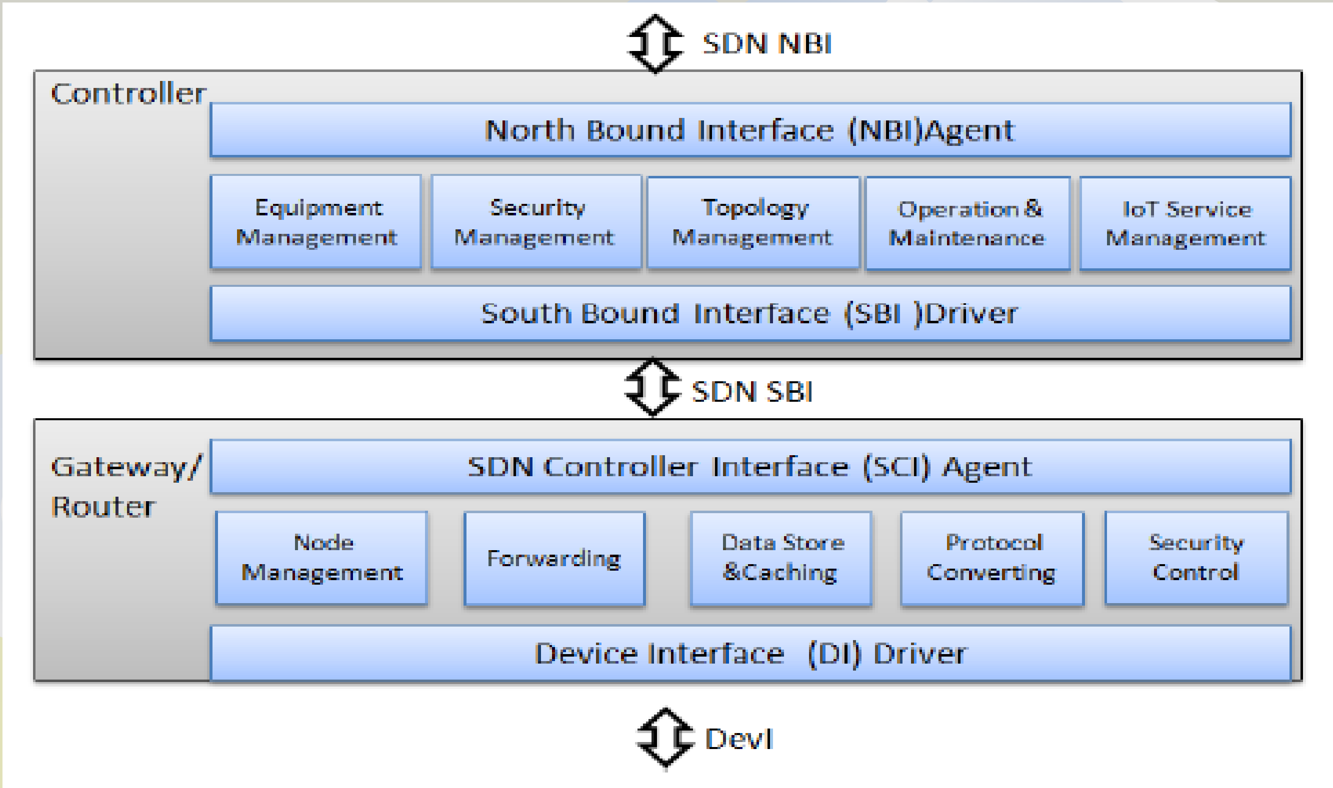
- **SDN control of IoT- example 1**



Source: Y.Li, et.al, "A SDN-based Architecture for Horizontal Internet of Things Services", ICC Conference, 2016

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

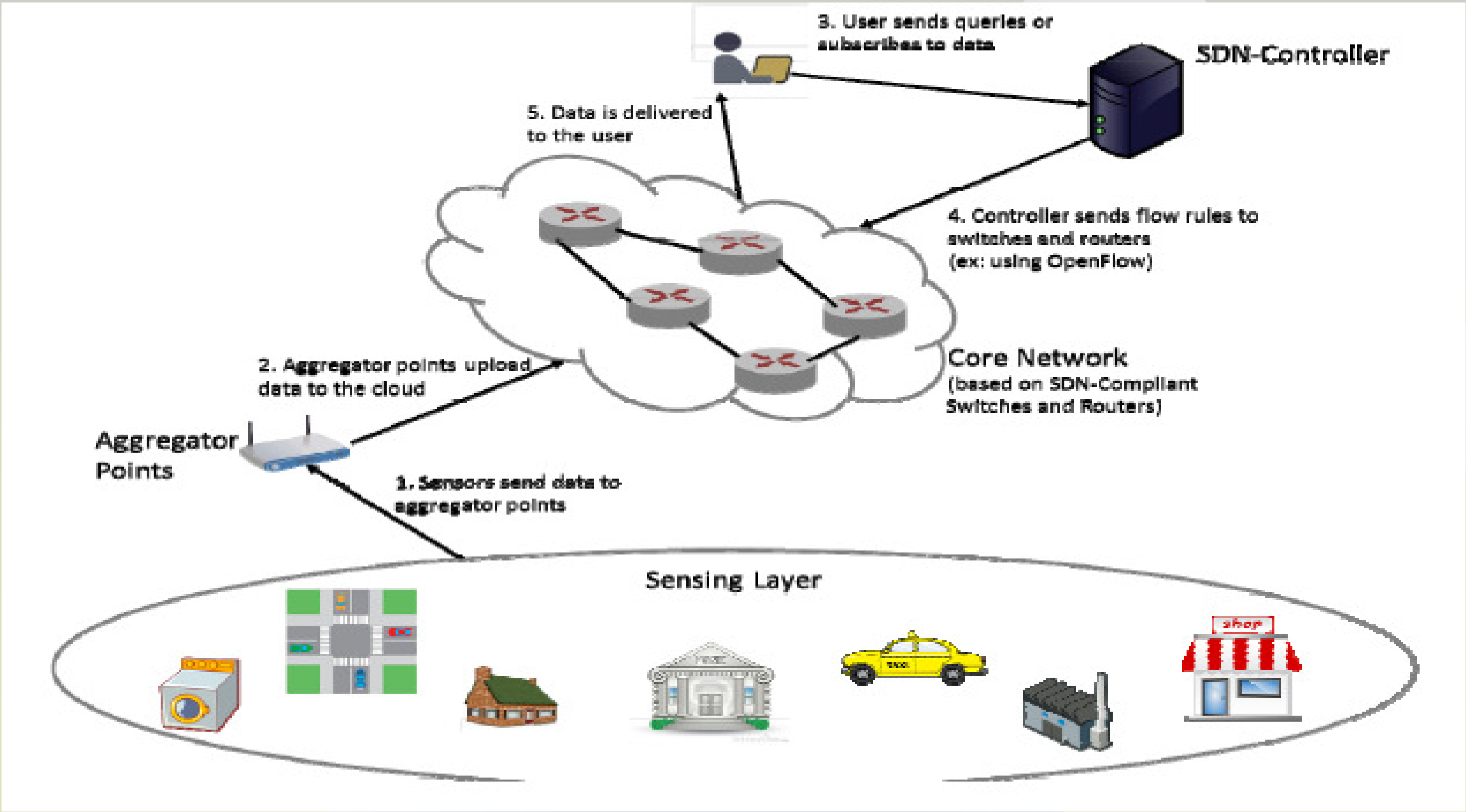
- **SDN control of IoT- example 1 (cont'd)**
- **Functional modules of the controller and gateways**



Source:Y.Li, et.al, "A SDN-based Architecture for Horizontal Internet of Things Services", ICC Conference, 2016

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

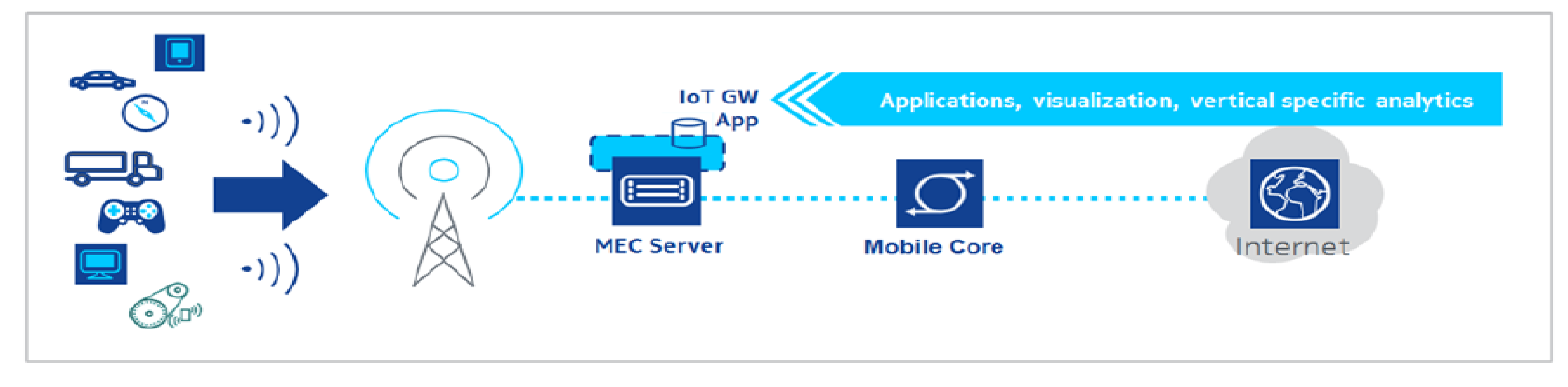
- **SDN control of IoT- example 2 (ICN-style architecture)**



Source: Amr El-Mougy, et.al., "Software-Defined Wireless Network Architectures for the Internet-of-Things", LCN 2015, Florida, USA

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **MEC Use Cases example- IoT**
- Internet of Things (IoT)
  - IoT devices: Often limited (processor, memory capacity)→ need for messages aggregation , security , low latency ..
  - r.t. capability → grouping of sensors and devices is needed for efficient service.
  - Possible Solutions:
    - IoT manipulated close to the devices (e.g., MEC server)
    - This also provides an analytics processing capability and a low latency response time.



Source: Yun Chao Hu et.al., "Mobile Edge Computing A key technology towards 5G" ETSI White Paper No. 11 September 2015, ISBN No. 979-10-92620-08-5

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Conclusions**
- Significant effort exist towards convergence/cooperation
  - **Technologies**
    - SDN- NFV
    - SDN- NFV- 4G-5G
    - CC- EC/Fog- 5G
    - EC/Fog-MEC- Cloudlets
    - CC-SDN-NFV- IoV
    - CC-SDN-NFV- IoT
    - **Issues: eliminate parallelism and overlapping between standardization efforts……**
  - **Different functional and business aspects**
    - Management and control
    - Slicing and virtualization
    - Security, privacy
    - Scalability
      - Interoperability
    - Seamless deployment characteristics
    - Support for apps and services
  - **New business models**
  - ……

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- Thank you !

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **References**

1. ETSI- Network Functions Virtualization – Introductory White Paper, https://portal.etsi.org/nfv/nfv_white_paper.pdf
2. ETSI GS NFV 002 v1.2.1 2014-12, NFV Architectural Framework
3. ONF, "OpenFlow-Enabled SDN and Network FunctionsVirtualization," https://www.opennetworking.org/images/stories/downloads/sdn-resources/solutionbriefs/sb-sdn-nvf-solution.pdf;
4. https://www.sdxcentral.com/sdn-nfv-use-cases/
5. M.Mendonca, et. al., A Survey of Software-Defined Networking: Past, Present,and Future of Programmable Networks, 2014, http://hal.inria.fr/hal-00825087
6. Y.Li, et.al, "A SDN-based Architecture for Horizontal Internet of Things Services", ICC Conference, 2016
7. Amr El-Mougy, et.al., "Software-Defined Wireless Network Architectures for the Internet-of-Things", LCN 2015, Florida, USA
8. Yun Chao Hu et.al., "Mobile Edge Computing A key technology towards 5G" ETSI White Paper No. 11, September 2015, ISBN No. 979-10-92620-08-5

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Backup slides**

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **List of Acronyms**

- BS Base Station
- BSS Business Support System
- CC Cloud Computing
- CCN Content Centric Networking
- COTS Commercial-off-the-Shelf
- EC Edge Computing
- EPC Evolved Packet Core
- ETSI European Telecommunications Standards Institute
- FC Fog Computing
- FCN Fog Computing Node
- IoT Internet of Things
- LTE Long Term Evolution
- MEC Mobile Edge Computing
- M&O Management and Orchestration
- MME Mobility Management Entity
- NF Network Function
- NFV Network Functions Virtualization
- NFVI Network Functions Virtualization Infrastructure
- NO Network Operator
- NP Network Provider
- NS Network Service
- OSS Operations Support System
- SDN Software Defined Network
- SLA Service Level Agreement
- SP Service Provider

Intro to Panel on “Feeling the Pain of Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, …”

Tommy Svensson
Professor, PhD, Leader Wireless Systems
Department of Signals and Systems, Communication Systems Group
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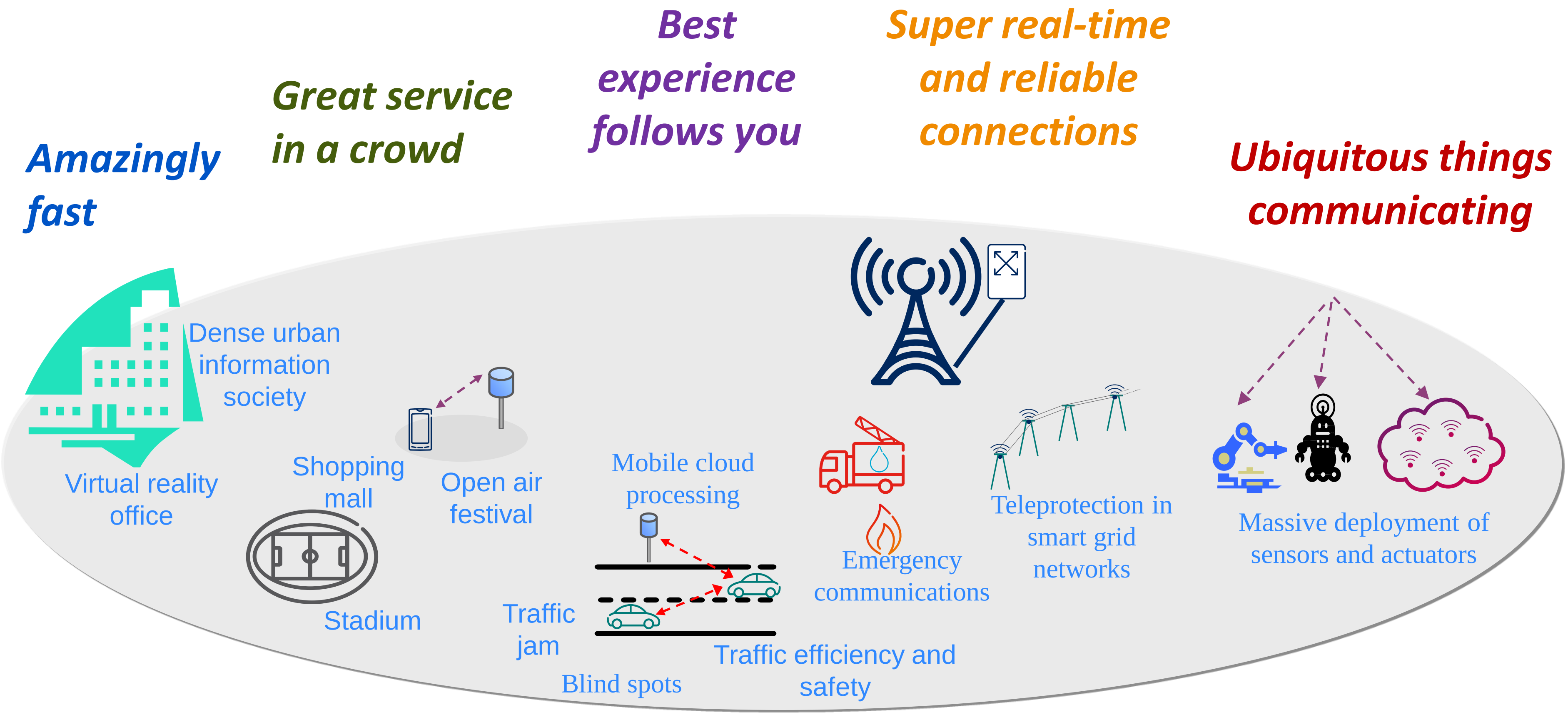
www.chalmers.se/en/staff/Pages/tommy-svensson.aspx

CHALMERS

METIS Scenarios and Test Cases



Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

Additional use cases has been proposed by NGMN Alliance, 'NGMN White Paper,' Feb. 2015 (available online https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf)

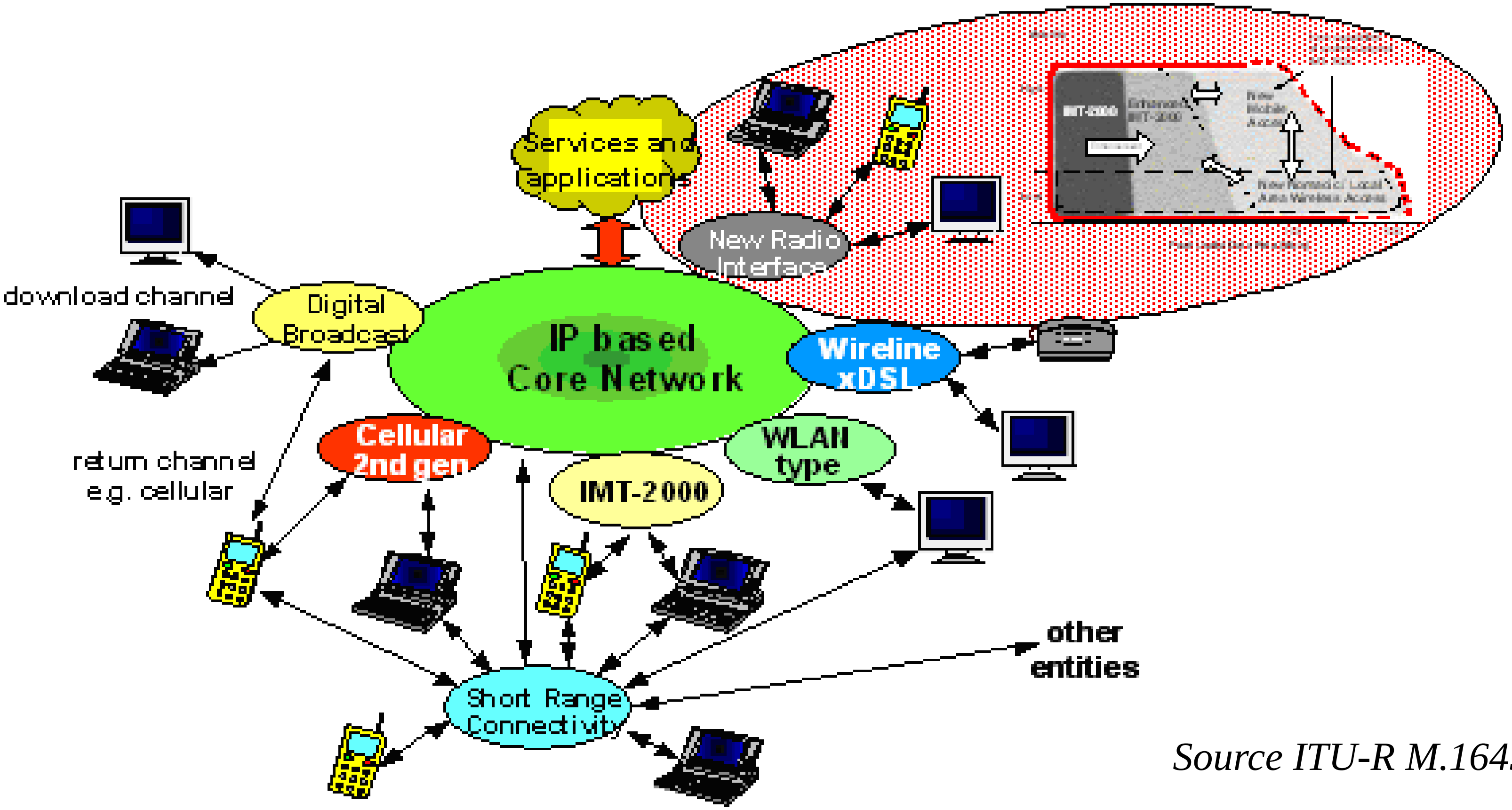
METIS Overall Technical Goal

A system concept that, relative to today, supports:

- 1000 times higher mobile data volume per area,
- 10 times to 100 times higher number of connected devices,
- 10 times to 100 times higher typical user data rate,
- 10 times longer battery life for low power Massive Machine Communication (MMC) devices,
- 5 times reduced End-to-End (E2E) latency.

Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

Recap: ITU-R Vision for Systems Beyond 3G



Source ITU-R M.1645

Integrate existing and evolving access systems on a *packet-based* platform to enable cooperation and interworking.

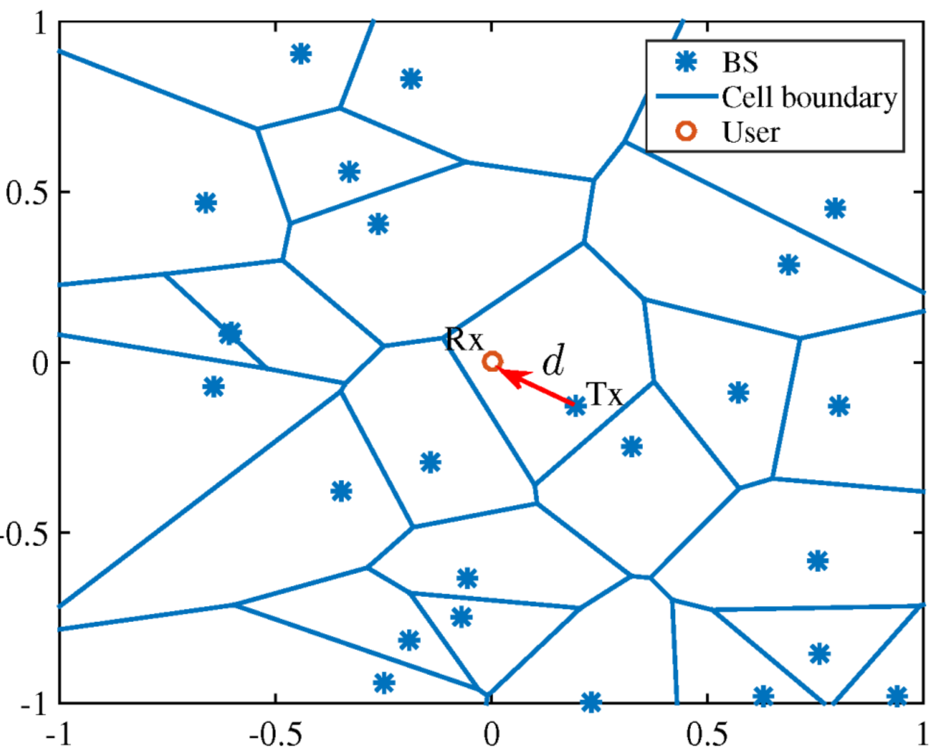
“Optimally connected anywhere, anytime"

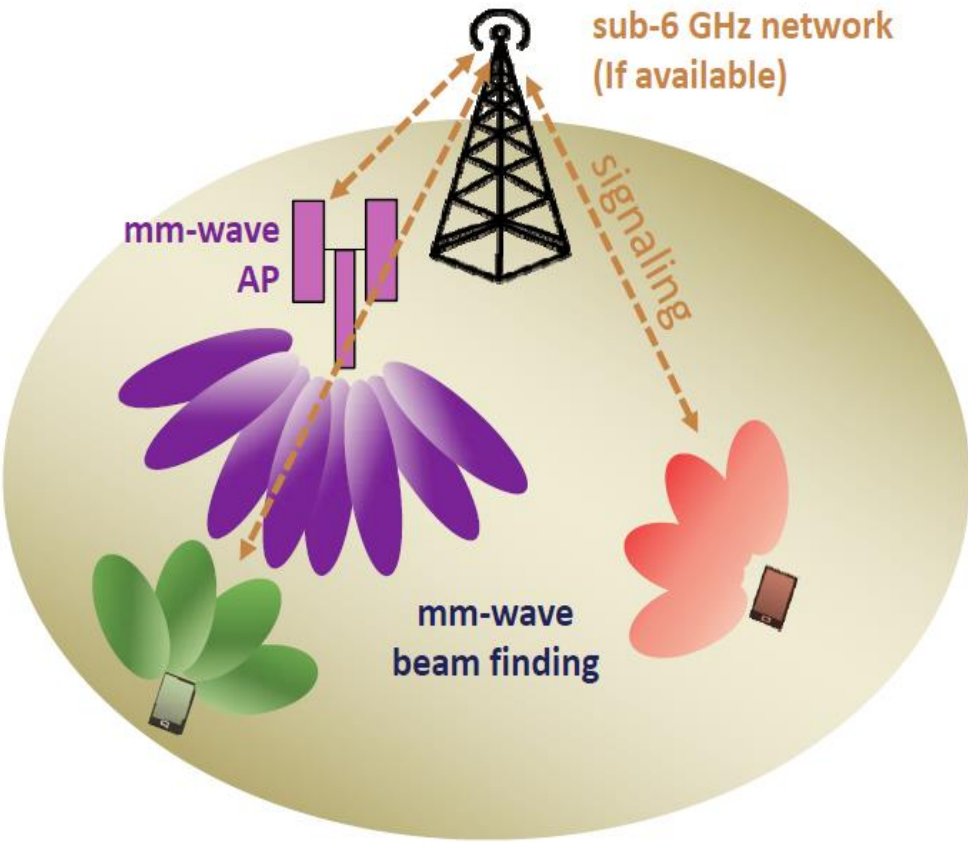
We have done it once already – On the terminal side!

Flexibility versus Efficiency

Picture source: http://onpr.com/choosing-the-right-smartphone-its-easy-to-decide/

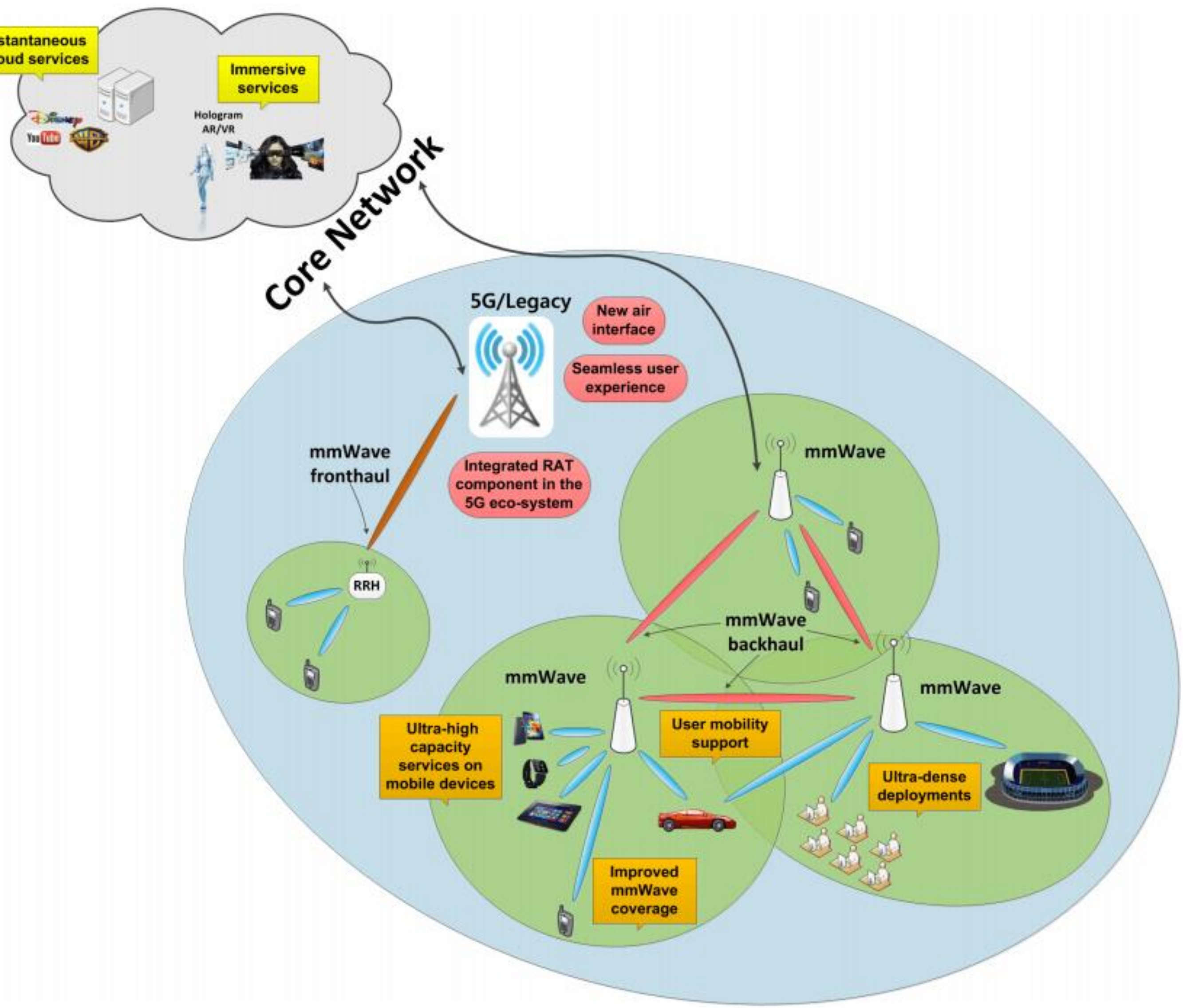
From hexagonal cells to unstructured beam spaces



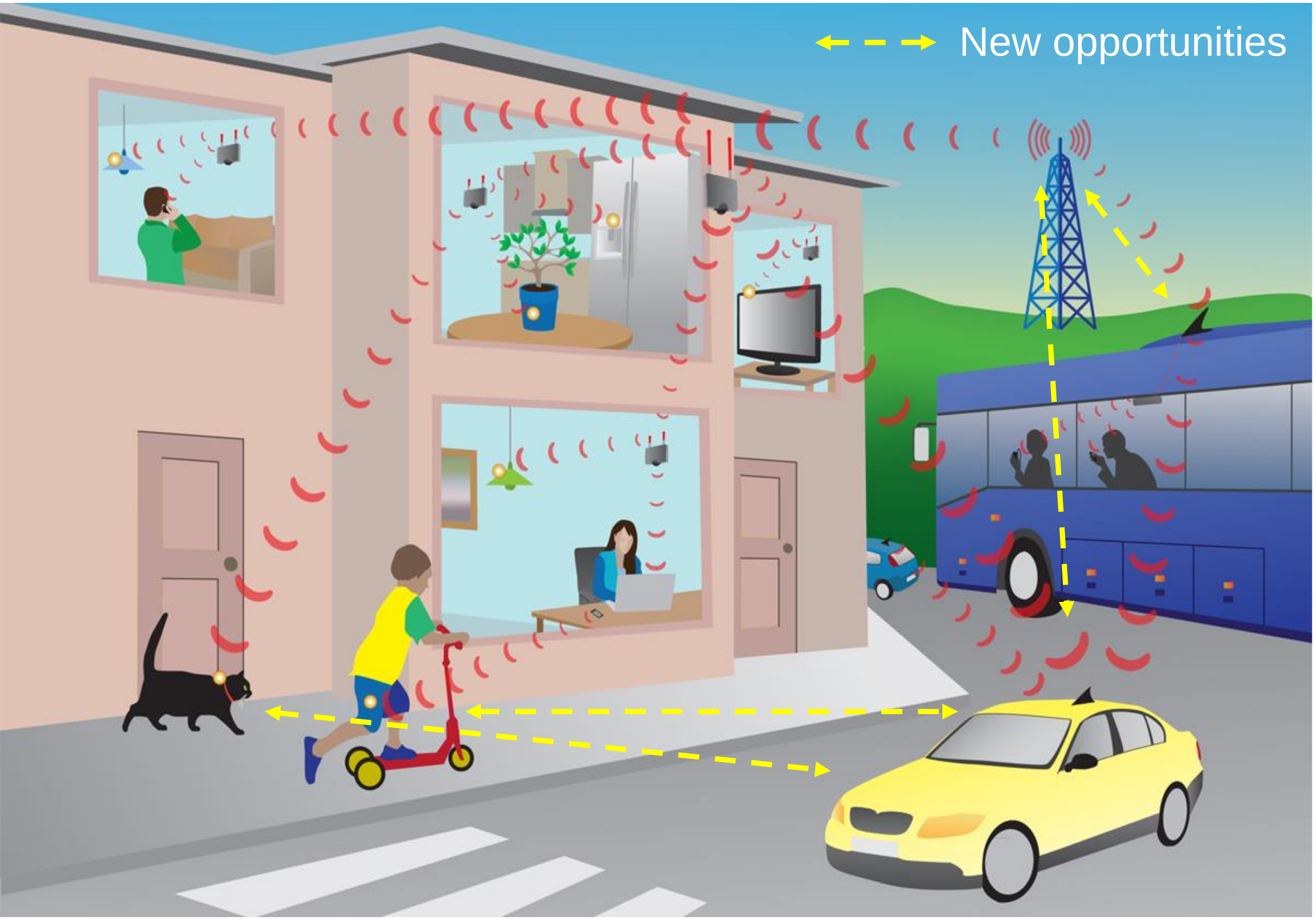


Source: mmMAGIC WP4 presentation, ETSI workshop, Sophia-Antipolis, Jan 28, 2016

Network slicing - Where should we do the computing?



Challenges and Opportunities with Demanding Verticals ”Integrated Moving Networks”



- **<u>Mutual benefits!</u>**
- **Better mobile systems efficiency**: Vehicles collect side information to improve the resource allocation and performance of the mobile network
- **More reliable V2X links**: Connect non-vehicular users to the Traffic Safety/Traffic Efficiency protocols (Pedestrians, cyclists, pets, …)
- **New disruptive business opportunities:** exploiting vehicle sensed data

The research leading to these results partly received funding from the European Commission H2020 programme under grant agreement no671650 (5G-PPP mmMAGIC project).

THANK YOU!

Find out more at https://5g-mmmagic.eu

Public deliverables: https://5g-mmmagic.eu/results/#deliverables

D1.1: “Use cases characterization, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz”, released 2015-11-30
D5.1 ”Initial multi-node and antenna transmitter and receiver architectures and schemes” released 2016-03-31
D4.1 ”Preliminary radio interface concepts for mm-wave mobile communications”, released 2016-06-30
D3.1 ”Initial concepts on 5G architecture and integration”, released 2016-03-31
D2.1 “Measurement campaigns and initial channel models for preferred suitable frequency ranges”, released 2016-03-31

mmMAGIC

6th Globecom'2017 Workshop on International Workshop on Emerging Technologies for 5G and Beyond Wireless and Mobile Networks (ET5GB)

Mon or Fri Dec 4 or 8, 2017, Singapore

Main topics:

- Novel radio access network (RAN) architectures
- Advanced radio resource management (RRM) techniques
- Emerging technologies in physical layer
- Novel services
- mmWave communications
- Energy efficiency
- Spectrum
- Prototype and test-bed for 5G and beyond technologies

Workshop Chairs:

- Wei Yu, University of Toronto, Canada
- Tommy Svensson, Chalmers U. of Technology, Sweden
- Lingjia Liu, University of Kansas, USA

Technical Program Chairs:

- Halim Yanikomeroglu, Carleton University, Canada
- Charlie (Jianzhong) Zhang, Samsung Electronics, USA
- Peiying Zhu, Huawei Technologies, Canada

http://wcsp.eng.usf.edu/5g/2017 (to appear) http://wcsp.eng.usf.edu/5g/2016

http://www.ieee-globecom.org/

From concept to deployment: the visions of the 5GCHAMPION and 5G-MiEdge projects

(Olympic Games are coming …)

Valerio Frascolla
Intel

2017.04.27, COCORA 2017, Venice

5GCHAMPION (www.5g-champion.eu)

- *Project name: 5G Communication with a Heterogeneous, Agile Mobile network in the Pyeongchang Winter Olympic Competition*
- *Funding scheme: FP8, Europe-Korea co-funding*
- *Duration: 2016.06 – 2018.05*
- *Key Targets:*
  - The first 5G proof-of-concept in conjunction with the 2018 Korean Winter Olympics,
  - Synergize satellite and terrestrial technologies,
  - Strong impact on Standards bodies.

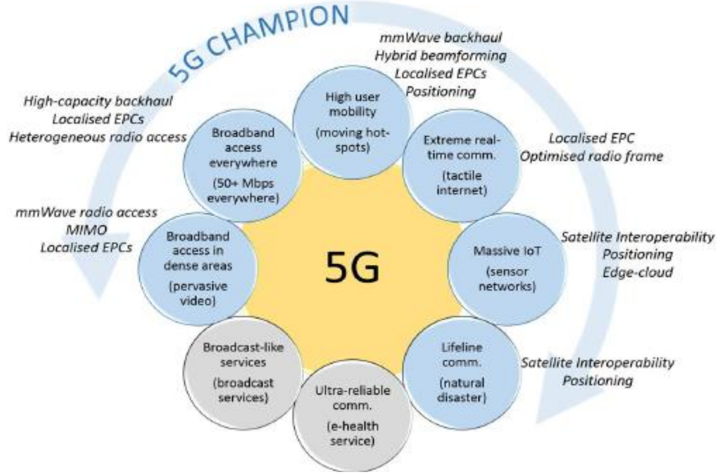
Europe

1. CEA-Leti (Coordinator), France
2. Nokia, Finland
3. Intel, Germany
4. Thales Alenia Space, France
5. University of Oulu, Finland
6. Fraunhofer HHI, Germany
7. Telespazio, France
8. iMinds, Belgium

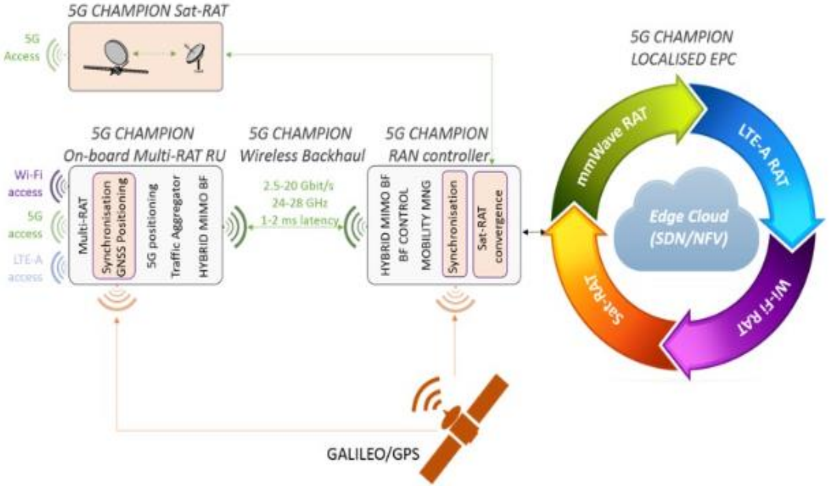
Rep. of Korea

1. ETRI (Coordinator)
2. Seoul Metropolitant Rapid Transit
3. South Korea Telecom
4. HFR
5. Clever Logic
6. Seoul National University
7. Dankook University
8. Hanyang University
9. Korea Telecom
10. Eluon
11. InSoft
12. Mobigen
13. Gwangju Institute of Science and Technology

5GCHAMPION



5G CHAMPION SYSTEM CONCEPT IMPLEMENTATION



- *Main technology enablers:*
  - mmWave Backhauling,
  - mmWave transceivers with reconfigurable antennas,
  - Localised evolved packet core supported by distributed or centralized mobile edge clouds with caching,
  - Media streaming functionalities,
  - Satellite radio access,
  - Satellite-terrestrial positioning.

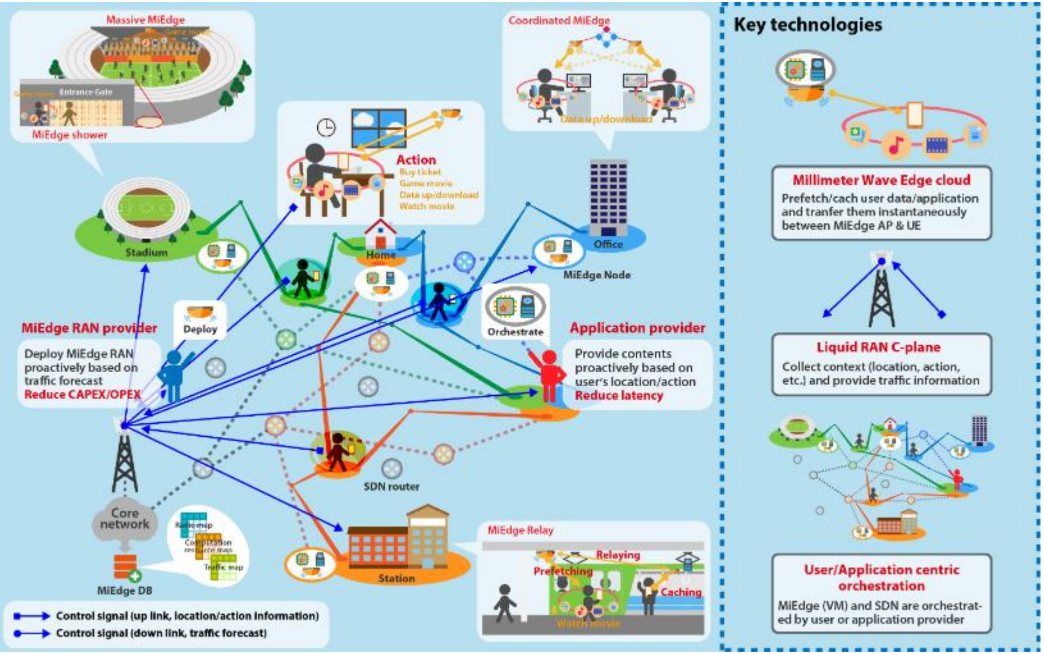
5G-MiEdge (5g-miedge.eu)

- Name: Millimeter-wave Edge Cloud as an Enabler for 5G Ecosystem

- Funding scheme: FP8, Europe-Japan co-funding, 2016.06 – 2019.05

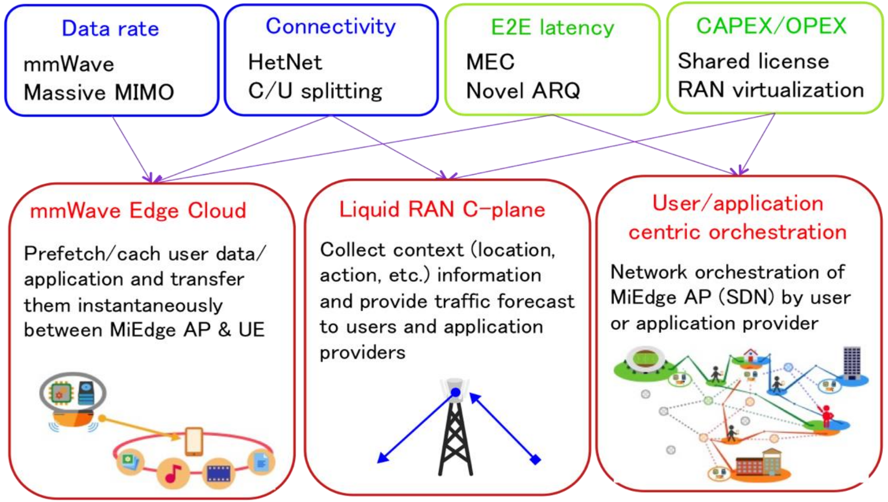
- *Key Target:*
  - 5G proof-of-concept in conjunction with the 2020 Japanese Summer Olympics.

- *Key technology enablers:*
  - mmWave Access & Backhaul,
  - User/Application Centric Orchestration,
  - Liquid RAN Control-plane:
    - novel ultra-lean and inter-operable control signaling over 3GPP LTE to provide liquid ubiquitous coverage in 5G networks, based on acquisition of context information and forecasting of traffic requirements.

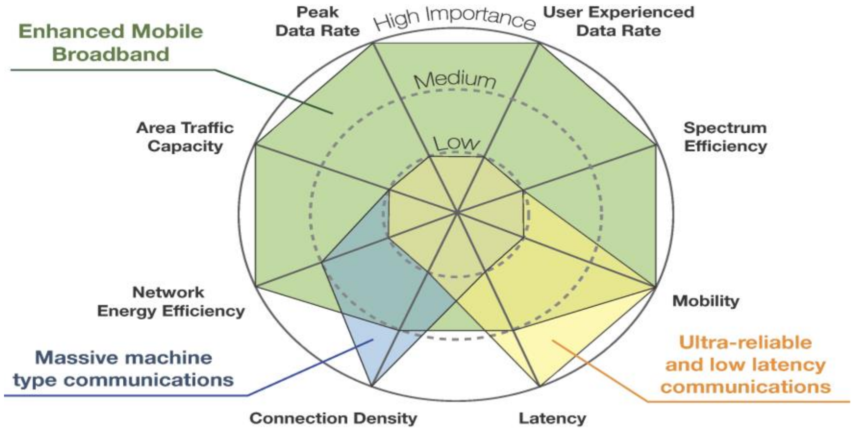


5G-MiEdge

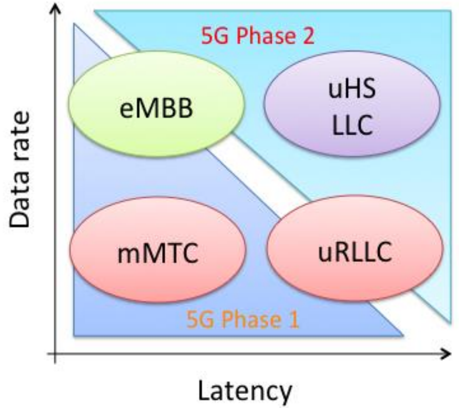
- Main research directions:
  - Focus on the ultra High-Speed and Low Latency Communications (uHSLLC) use cases and related technology enablers
  - Synergize between mmWave and MEC technologies



Technology enablers for uHSLLC and related KPIs



5G KPI defied in IMT-2020



Q&A

➢Questions?

Disclaimers

5G-MiEdge: The research leading to these results are jointly funded by the European Commission (EC) H2020 and the Ministry of Internal affairs and Communications (MIC) in Japan under grant agreements N° 723171 5G MiEdge in EC and 0159-{0149, 0150, 0151} in MIC.

5GCHAMPION: The research leading to these results was supported by the Institute for Information & communications Technology Promotion (IITP) grant, funded by the Korea government (MSIP) (No.B0115-16-0001, 5GCHAMPION), and received funding from European Union H2020 5GPPP under grant n. 723247.

Intel Communication and Devices Group

5G for people and things
Key to the programmable world

Overview

5G Radio Interface

- Worldwide cm and mm bands to enable Gbps user rates. [Revolution]
- Massive MIMO technologies to help cm and mm wave technologies. [Revolution]
- Performance Results
- Dynamic TTI [Evolution]
- Multi-connectivity xRAT [Evolution]

5G IoT

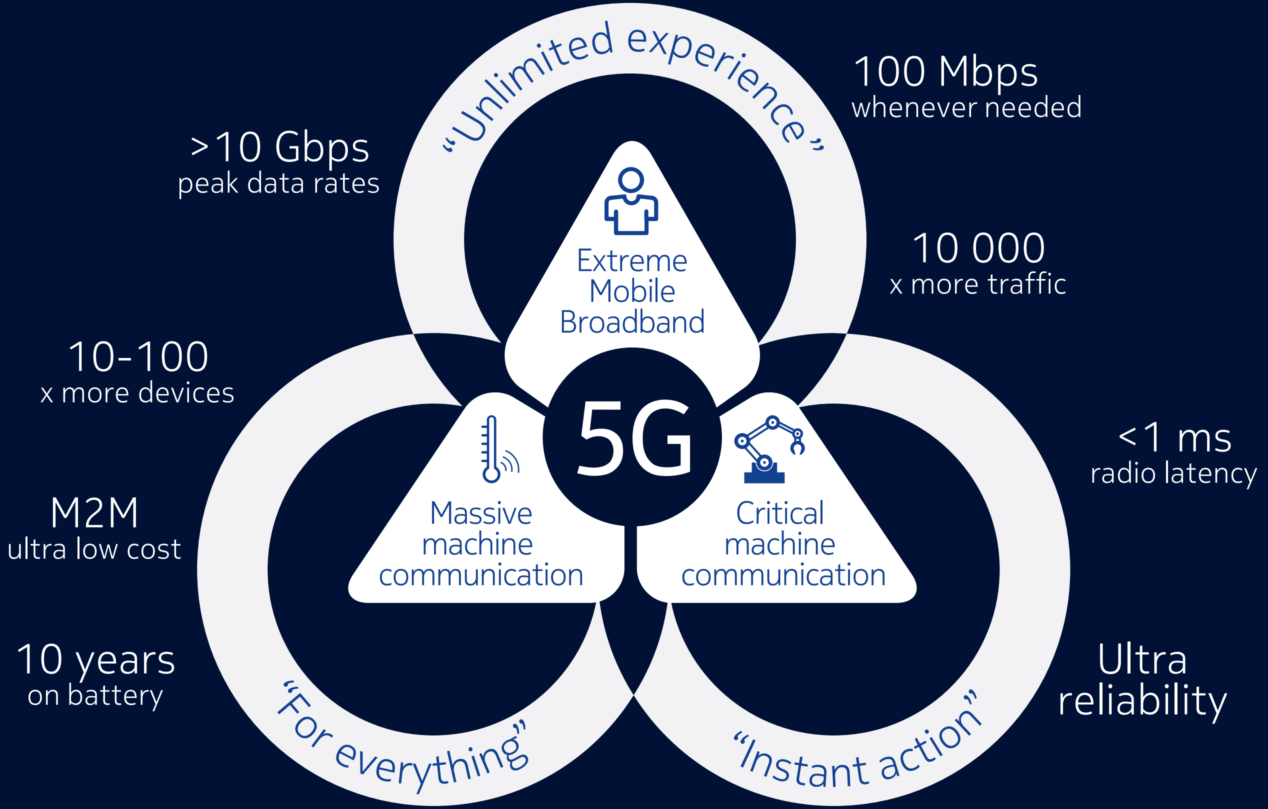
- Cat-M and NB-IOT [Evolution]
- New air inteface to optimize IOT? [Revolution]

5G Networking

- Network slicing [Evolution]
- Flexibility [Revolution]

5G involves two things: **what** we innovate on and **how** we do it.

Diverse requirements [MBB vs IoT]



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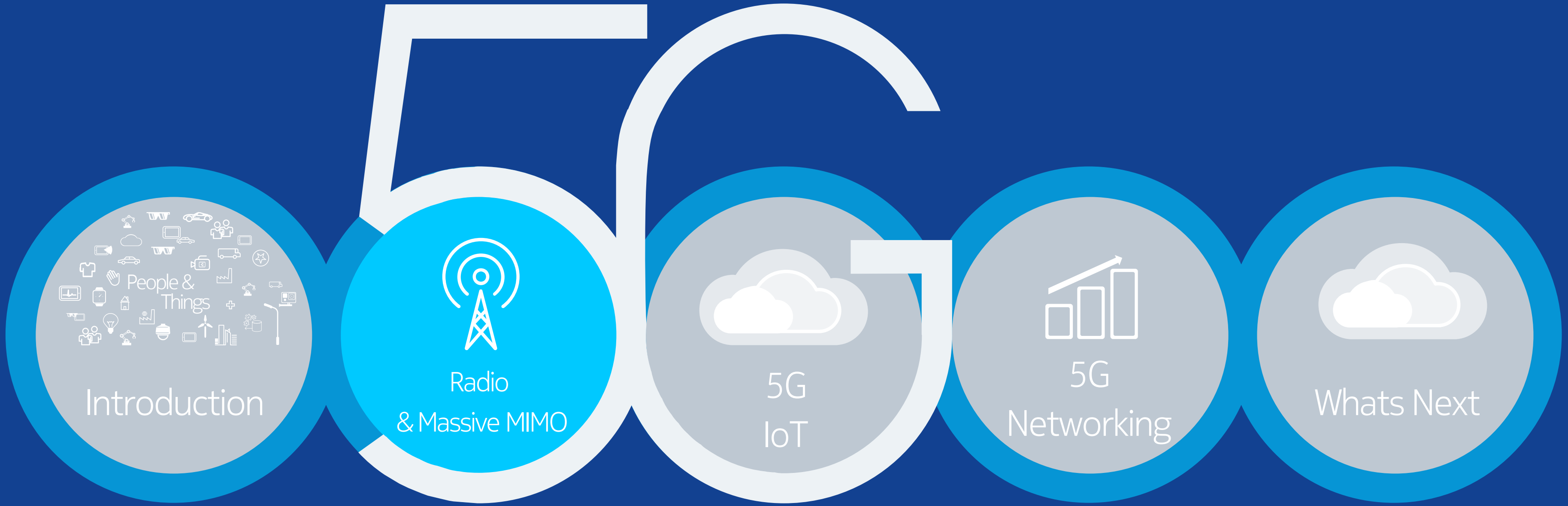
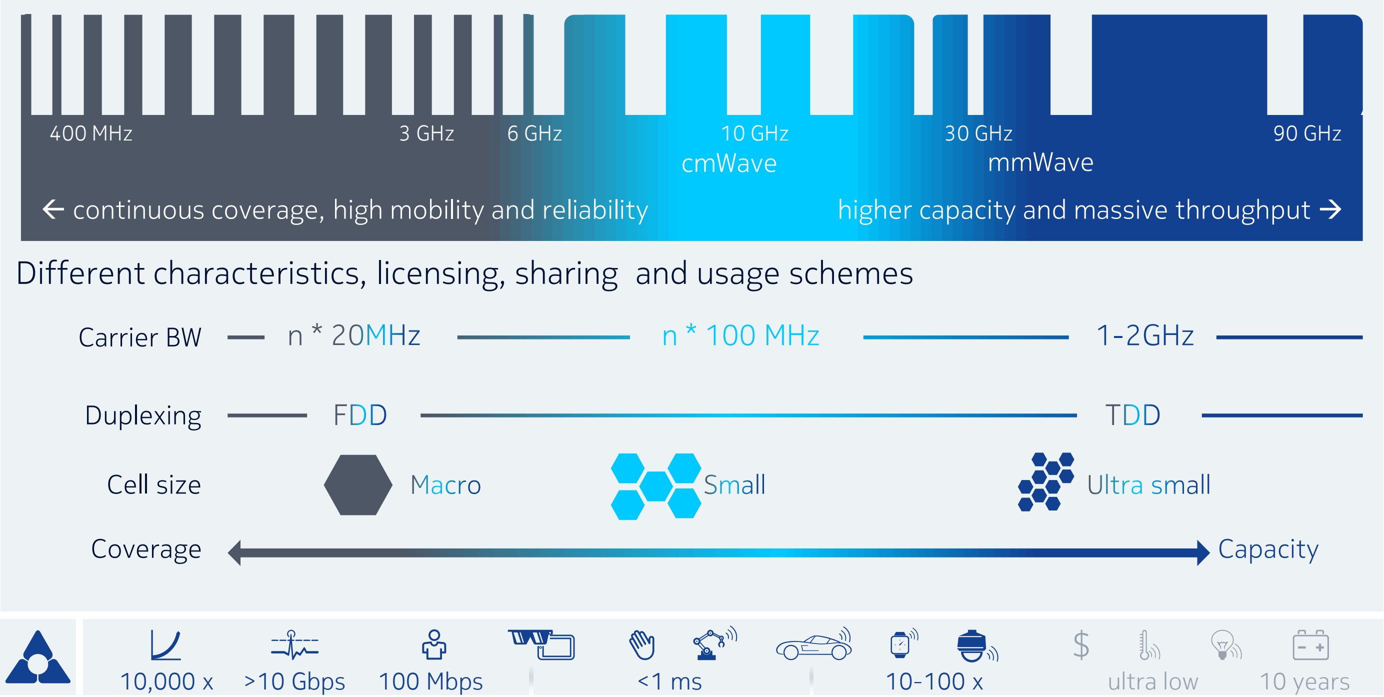
NOKIA



Key to the programmable world

Unlocking new spectrum assets | Foundation for 5G

Leveraging all bands , ranging from ~400MHz - 100GHz



Leading METIS I & II spectrum work package

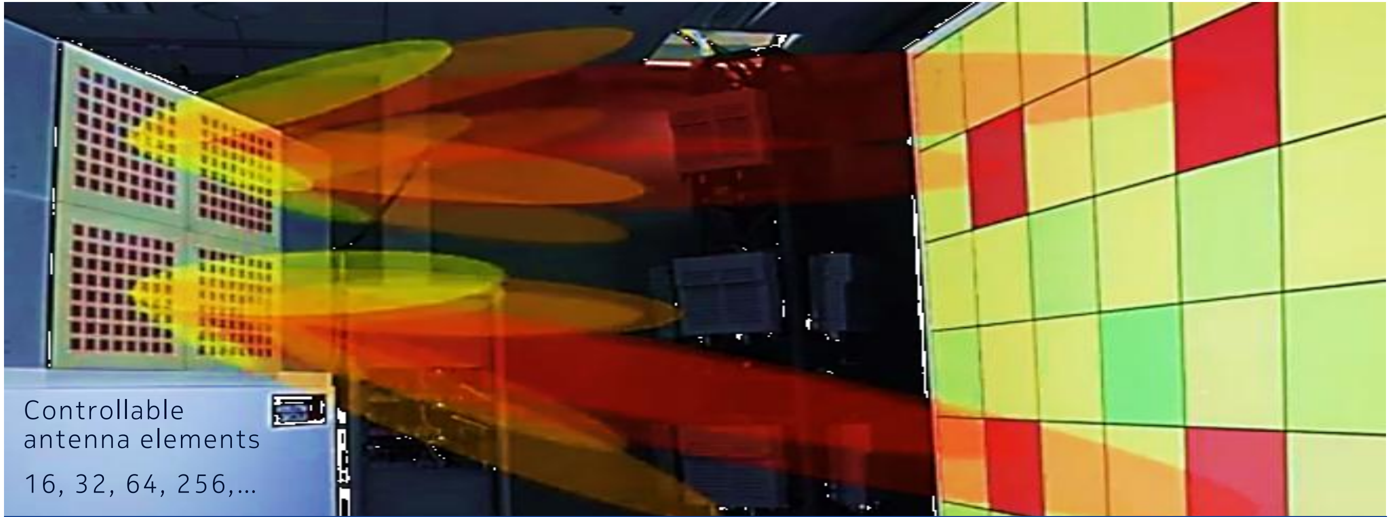
Leading modeling know-how
Channel measurements from 3-73GHz

World's 1st trials
on shared spectrum access

NOKIA

Native massive MIMO | Let the capacity follow the demand

Chip-scale antennas, high beamforming & multiplexing gain



Exploiting high frequency bands with chip scale antenna array research
→ Compensating path loss with high antenna gain

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | ultra low | 10 years

700%
Cell edge gain

+80%
Spectral efficiency

Cooperation with top notch industry and university partners

mmWave trials
with DOCOMO

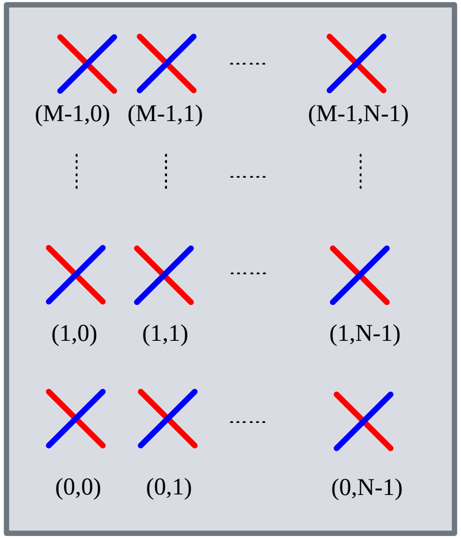
10Gbps speed record w. National Instruments

  public

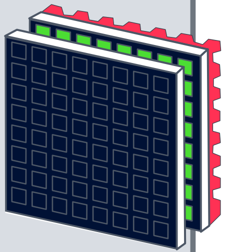
NOKIA

What is “Massive MIMO”?

- **Massive MIMO** is the **extension of traditional MIMO** technology to antenna arrays having a **large number** of **controllable antennas**



- MIMO = Multiple Input Multiple Output = **any transmission scheme involving multiple transmit and multiple receive antennas**
  - Encompasses all implementations:
    - RF/Baseband/Hybrid
  - Encompasses all TX/RX processing methodologies:
    - Diversity, Beamforming, Spatial multiplexing,
    - SU & MU, joint/coordinated transmission/reception, etc.
- **Massive ➔ Large number**: >> 8
- **Controllable antennas**: antennas (whether physical or otherwise) whose signals are adaptable by the PHY layer (e.g., via gain/phase control)



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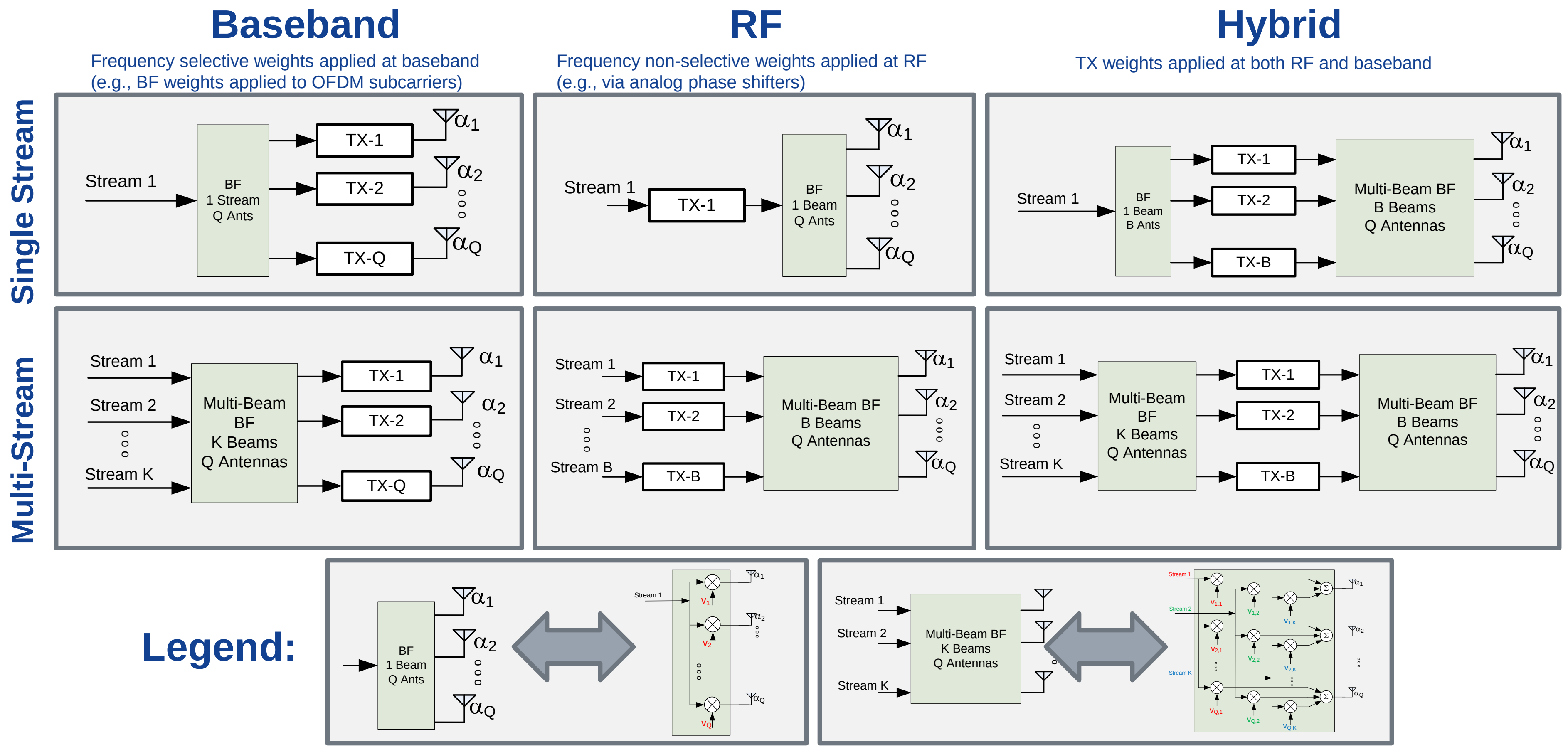
Why "Massive MIMO"

- Benefits:
  - **Enhance Coverage** ➔ High gain adaptive beamforming
    - Focus energy more towards the user, increase SINR
  - **Enhance Capacity** ➔ High order spatial multiplexing
    - Multiple parallel spatial streams to a single user (SU) or to multiple users (MU)
- Relevance to 5G:
  - Lower operating frequencies (e.g., <6GHz) are more interference limited
    - LTE already designed for high spectral efficiency (<8 Antenna ports)
    - **Capacity-enhancing solutions become essential**
  - Higher operating frequencies (e.g., >>6GHz) have poor path loss conditions
    - **Coverage-enhancing solutions become essential**

Signal Processing View: Fully Connected Arrays



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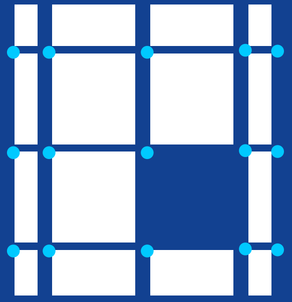
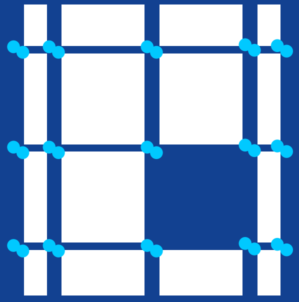
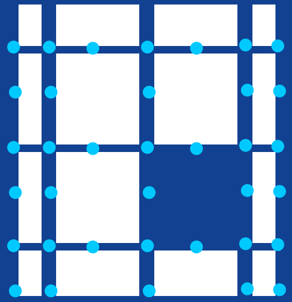
RF vs. Baseband vs. Hybrid Architectures

Baseband	RF	Hybrid
Adaptive TX/RX Weightings at Baseband	Adaptive TX/RX Weightings at RF	Adaptive TX/RX Weightings at both RF and Baseband
Single transceiver Per Antenna Port	Single transceiver per RF beam	Single transceiver per RF beam
“Frequency-Selective” Beamforming	“Frequency-Flat” Beamforming	Combination RF / Baseband
High Flexibility	Low Flexibility	Moderate Flexibility
High power consumption & cost characteristics	Better power consumption & cost characteristics	Good power consumption & cost characteristics

Performance of Massive MIMO @ mmWave
5G requirements can be met even in challenging environments

		
75 AP/km^2	150 AP/km^2	187 AP/km^2
		AP density
2.1 Gbps Average UE Throughput	4.1 Gbps Average UE Throughput	5.1 Gbps Average UE Throughput
<1 Mbps Edge Throughput	222 Mbps Edge Throughput	552 Mbps Edge Throughput
		Network capacity
16.4% Outage Probability	3.2% Outage Probability	1% Outage Probability

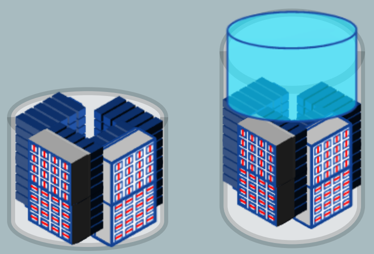
Multi-connectivity (72GHz / 2GHz BW)

Outage = less than 100Mbps throughput

Performance in outdoor environments

Enabled through

- flexible backhaul
- RFIC/antenna integration



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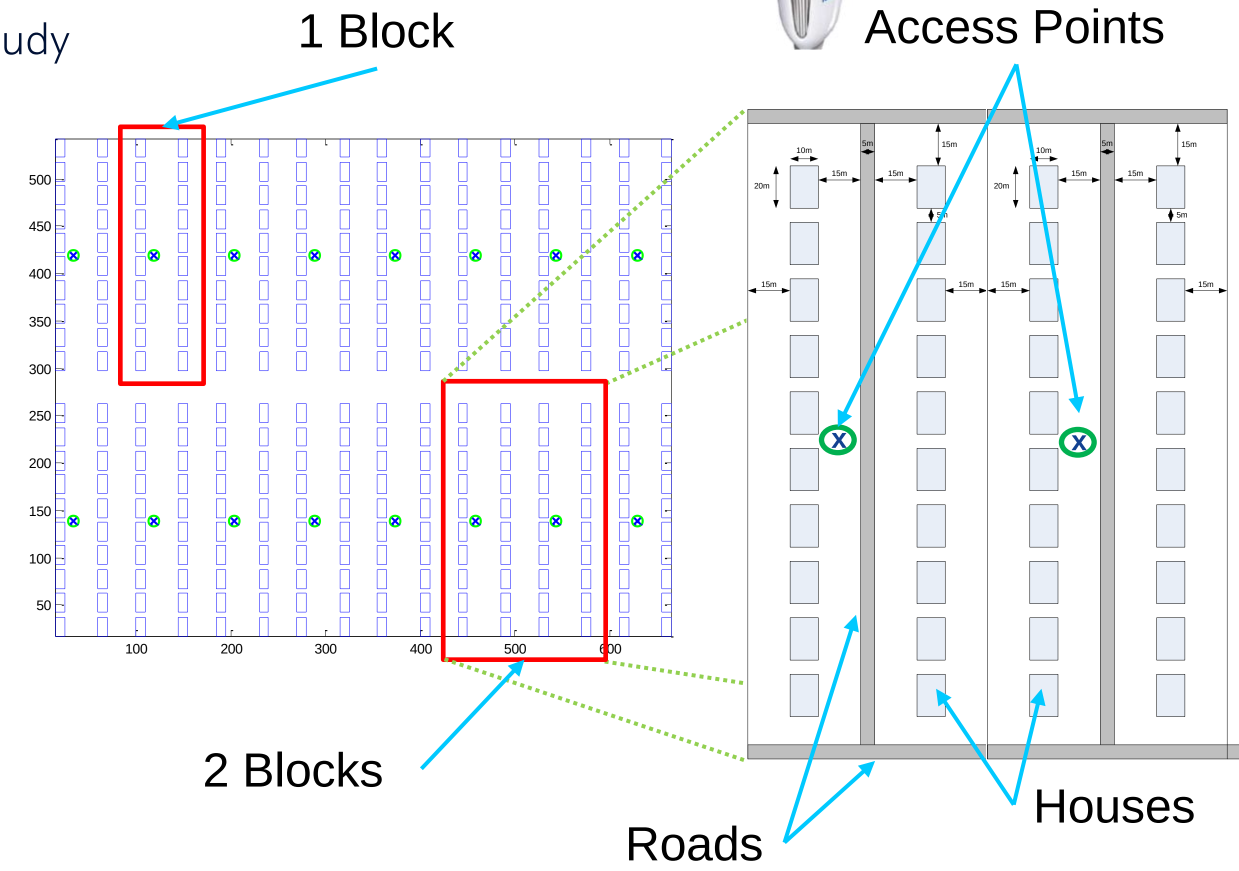
Wireless 5G to the Home at 39GHz

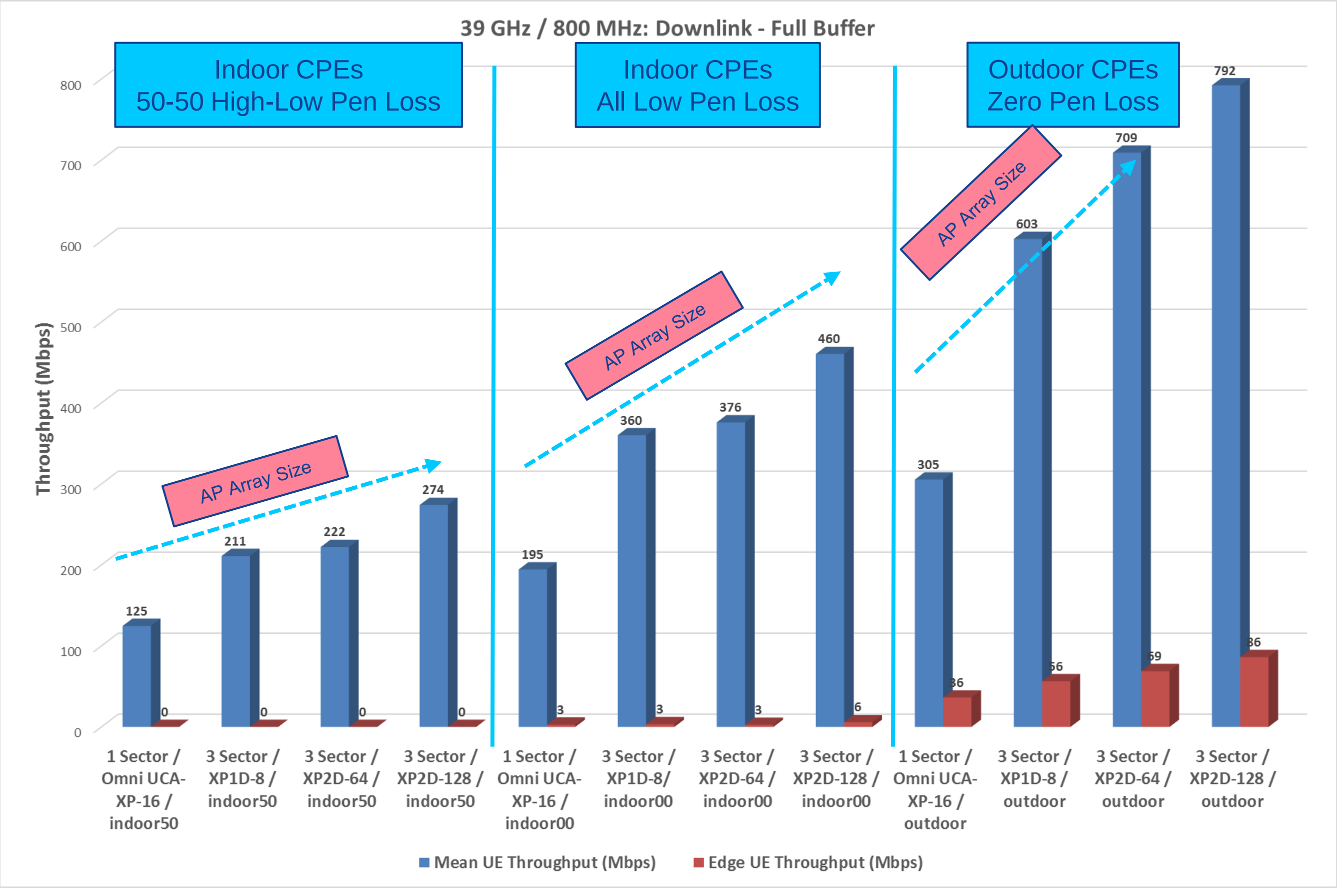
- Physical Layer Simulation Study

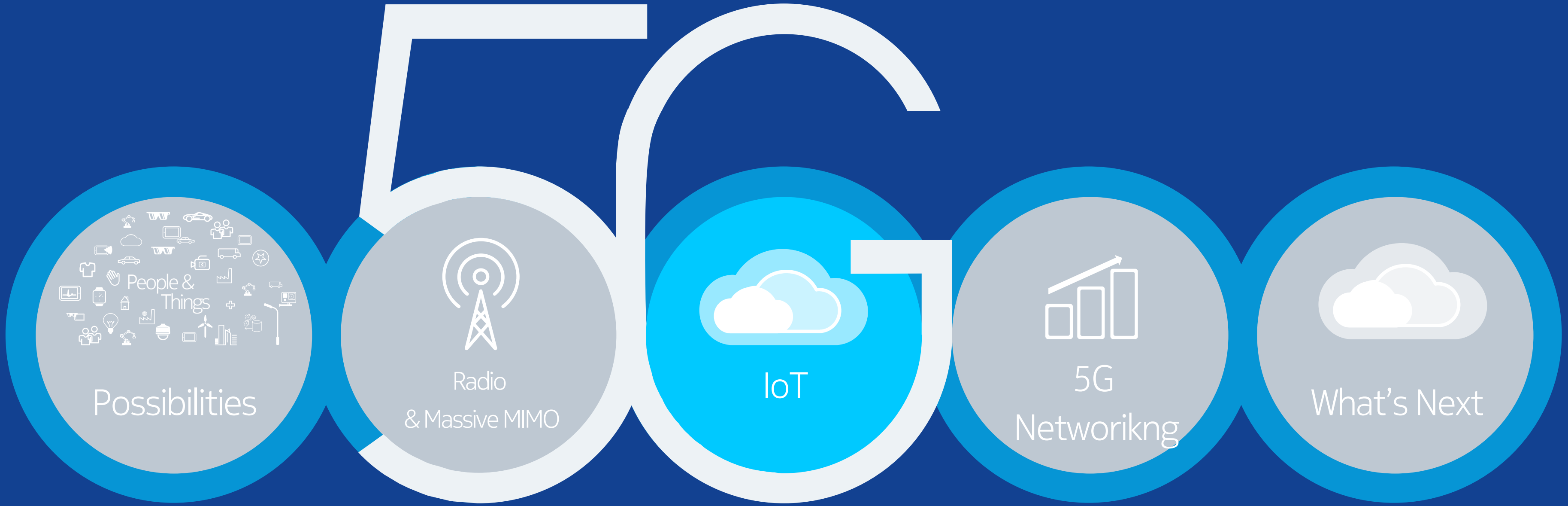


- Modified Detailed 3GPP/RAN1 physical layer system level simulator
- Suburban neighborhood layout of 320 houses, 16 blocks, 1 AP per block
- AP is either a single omni sector site or is a 3-sector site mounted on 6m high lamppost
- 10 active CPEs per AP site
- Indoor CPEs vs Outdoor CPEs
- Path Loss, Blockage, and Multipath Modeling appropriate for 39GHz
- Null Cyclic Prefix Single Carrier System with 800MHz Bandwidth

39 GHz NCP-SC, 800 MHz BW – Effect of Larger Antenna Arrays and Penetration Loss

- AP Arrays:
  - 1 Sector: Omni UCA-XP, **16** antennas
  - 3-Sector: XP1D, **8** antennas
  - 3-Sector: XP2D, **64** antennas
  - 3-Sector: XP2D, **128** antennas
- CPE: 2 antennas (omni)
- Antenna element gain:
  - For 1D arrays: antenna element gain = 14dBi
  - For 2D arrays: antenna element gain = 1dBi
- 10 CPEs per site on average





Key to the programmable world

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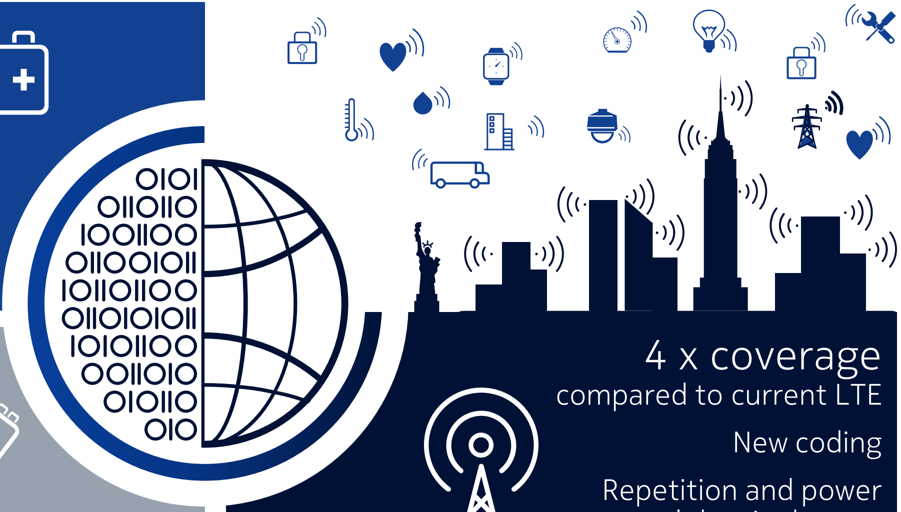
IoT | Low cost & power for massive machine type communication

LTE-M for small, infrequent & low cost data transfer

Power saving
Longer sleeping cycles*
Less signaling for wakeup
Power Save Mode

Simplified modems
Narrowband transmission
Reduced transmit power
Limited downlink transmission modes
UE processing relaxations
...



4 x coverage
compared to current LTE
New coding
Repetition and power spectral density boosts
+15~20 dB coverage

>10 years
Battery life with two AA batteries

Very low device cost

Live trial with KT

MWC 2015
First live demo
on commercial Nokia FlexiZone and core

Driving for availability in 3GPP Rel.13, 2016

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | $ | ultra low | 10 years

*) Extended Discontinuous Reception (DRX)

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Main LTE-M & NB-IoT features

- 3GPP specifications in Release 12 and 13

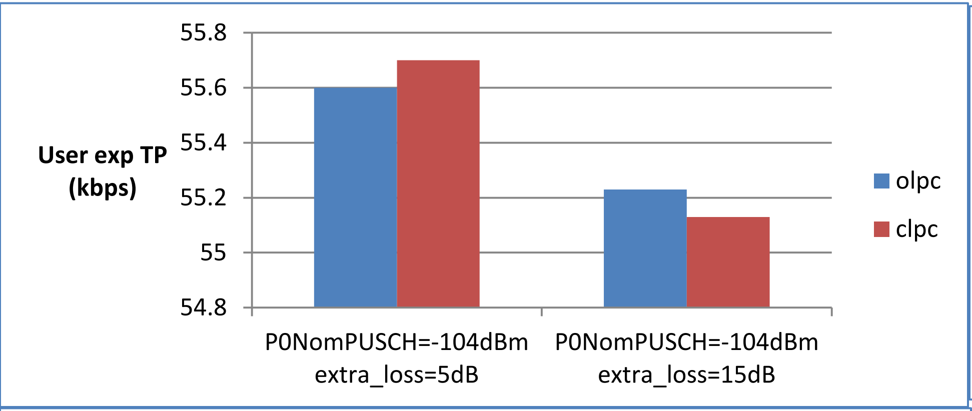
Release 12 introduced low complexity UE category ("Cat-0") with lower data rate, half duplex and single antenna.

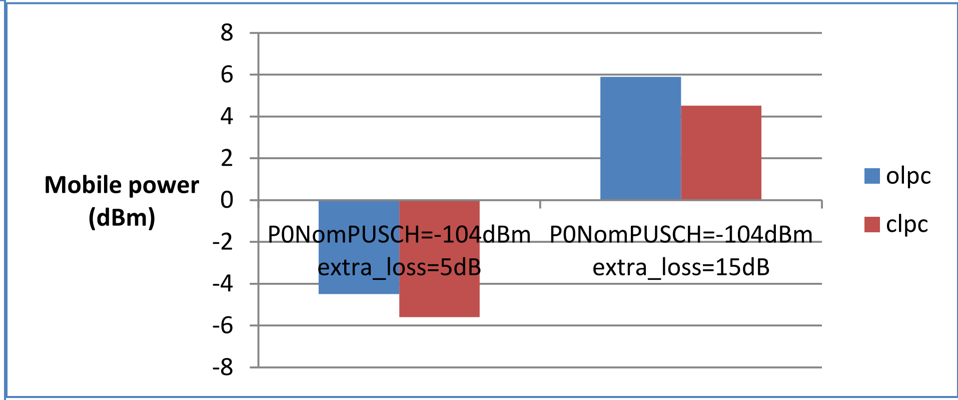
Release 13 will further reduce UE device complexity with narrowband RF and lower peak data rates.

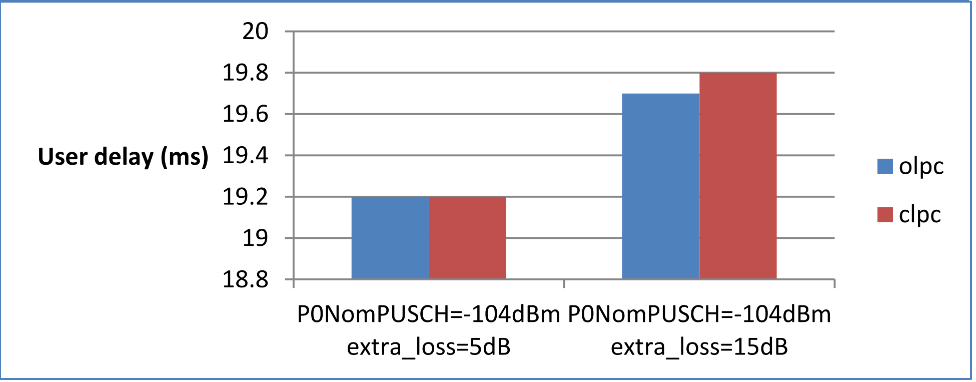
3GPP LTE	Release 8	Release 8	Release 12	Release 13	
UE characteristics	**Cat. 4**	**Cat. 1**	**Cat. 0**	**Cat. M**	**NB-IoT**
Downlink peak rate	**150 Mbps**	**10 Mbps**	**1 Mbps**	**1 Mbps**	**200 kbps**
Uplink peak rate	**50 Mbps**	**5 Mbps**	**1 Mbps**	**1 Mbps**	**144 kbps**
Number of antennas	2	2	1	1	1
Duplex mode	Full duplex	Full duplex	Half duplex	Half duplex	Half duplex
UE receive bandwidth	20 MHz	20 MHz	20 MHz	1.4 MHz	200 kHz
UE transmit power	23 dBm	23 dBm	23 dBm	20 dBm	23 dBm
Maximum signal loss	**<140 dB**	**<140 dB**	**<140dB**	**156 dB**	**164 dB**
Modem complexity	100%	80%	40%	20%	<15%

M-PUSCH Closed loop versus open loop (single cell)

- CLPC versus OLPC for a given P0NomPUSCH.





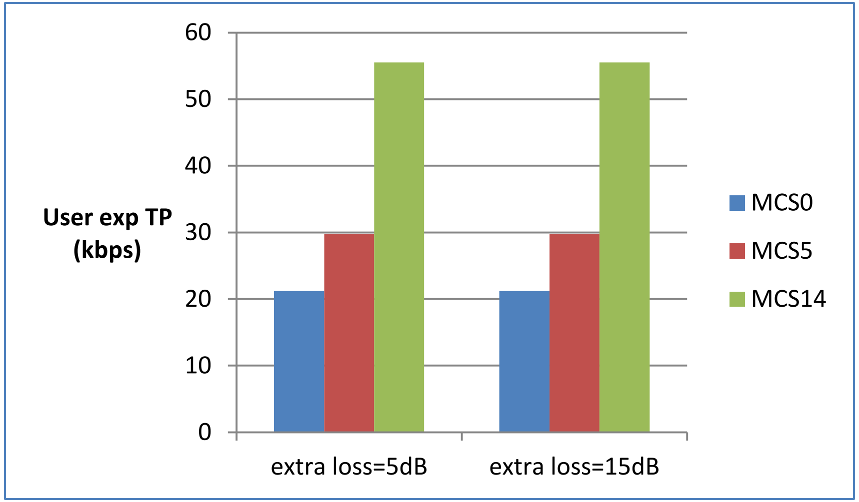


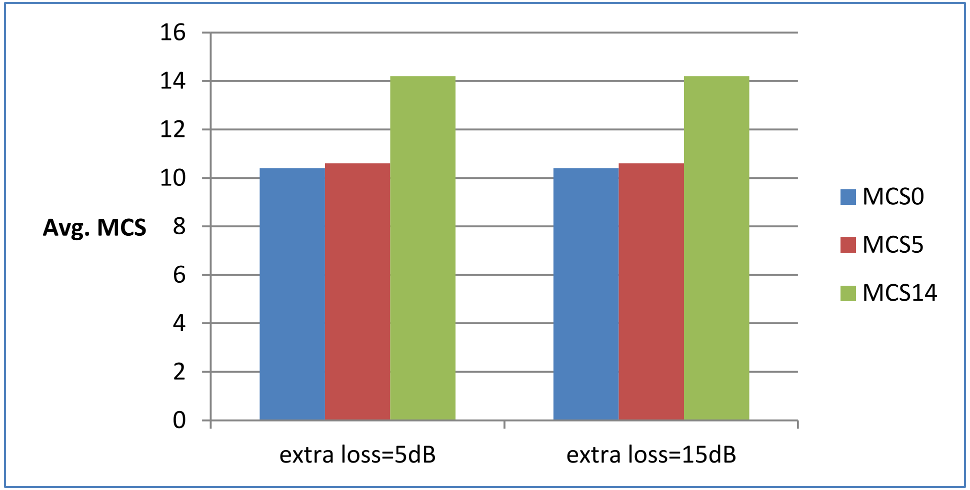
Performance is about the same between CLPC and OLPC. CLPC does seem to use lower transmission power.

OLPC has the about the same performance as CLPC in terms of throughput and delay but uses higher transmit power .

M-PUSCH - Impact of initial MCS(single cell)

- OLPC, PoNomPUSCH=-114dBm

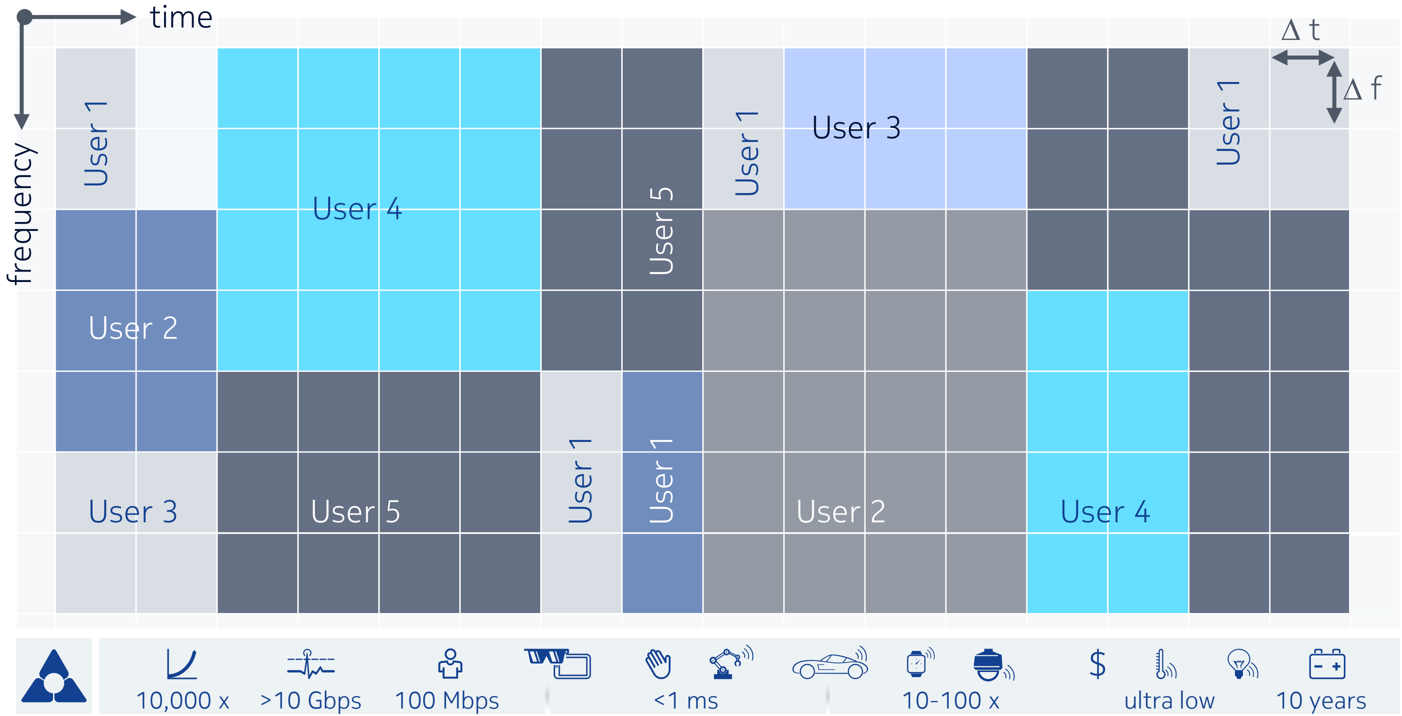




- Performance is sensitive to the initial MCS.
- Note: msg3 is not modeled here which could serve as a M-PUSCH measurement.

Initial MCS impacts performance .

Dynamic TTI: Flexibility in supporting MBB and IoT



*) compared to static TD-LTE

50-100%
capacity gain*

Smart local traffic routing e.g. D2D on top of local cellular

SC/UDN low cost deployment
e.g. via self-backhauling

Dynamic TDD cmW and mmW air IF blue prints and PoC

Part of eLA concept adopted in METIS

  public

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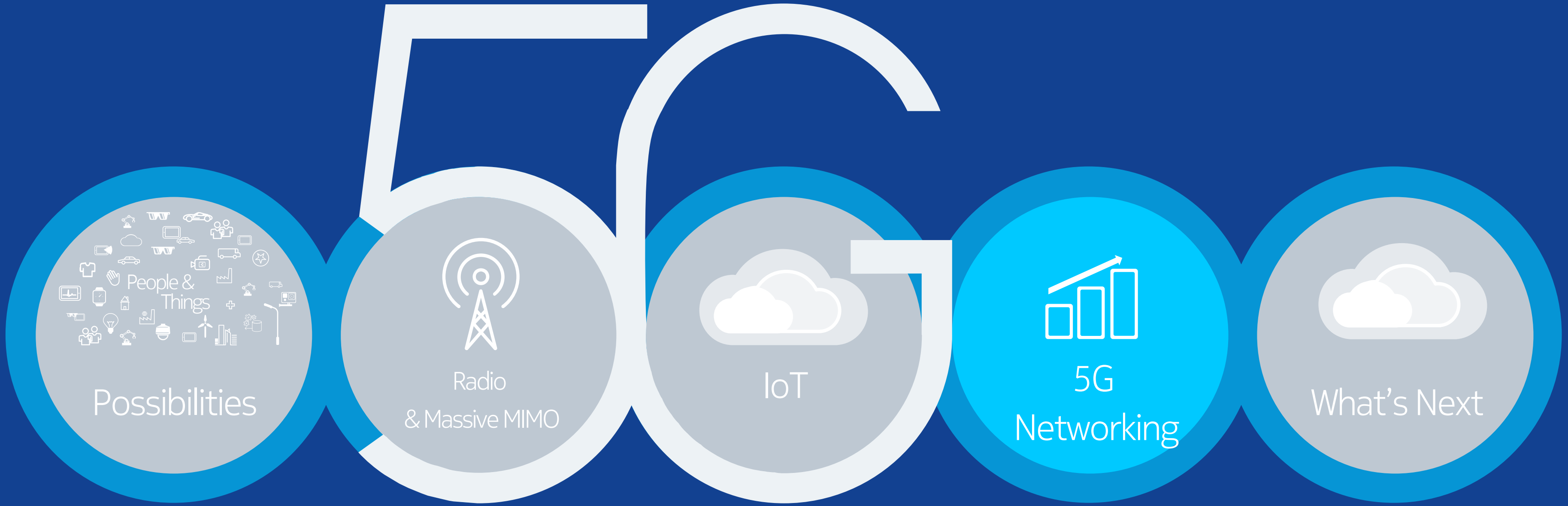

Key to the programmable world

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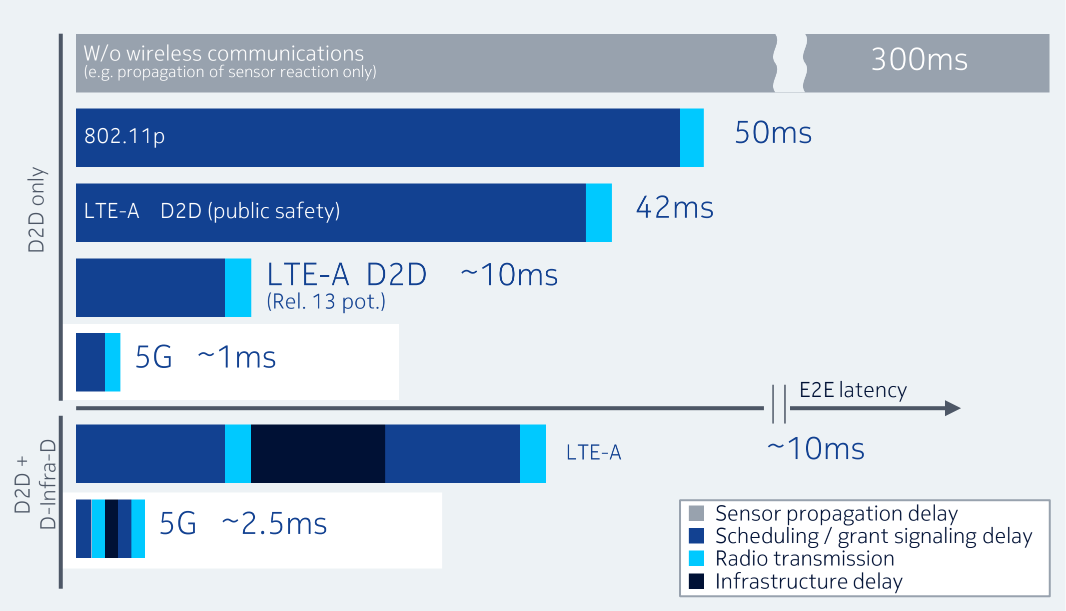
1ms Latency | Enabling a new generation of latency critical services

E2E latency aware scheduler

Latency optimized frame structure

Dynamic uplink-downlink

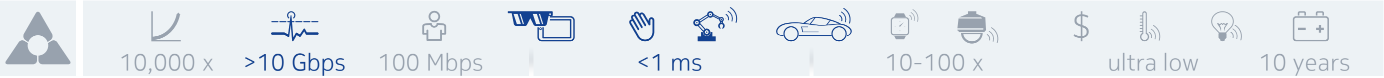
Pipeline processing



Autonomous driving and production

Tactile internet services

mmWave demo
with NTT DoCoMo



DMRS = Demodulation Reference Signal; GP = Guard Period

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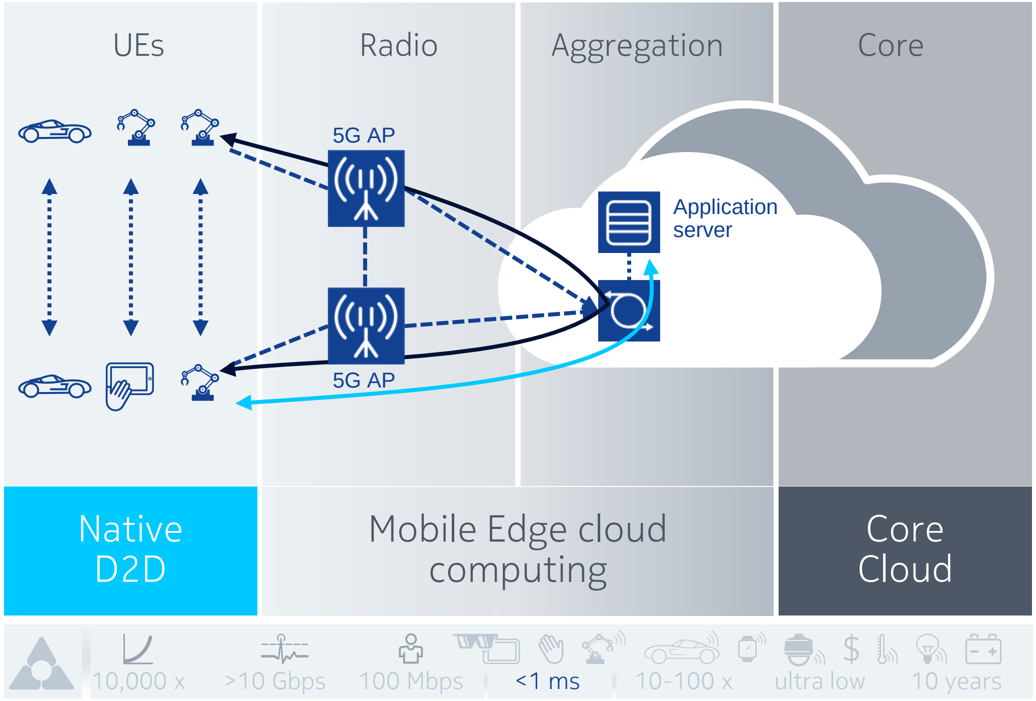
Fast traffic forwarding | Enabling a new generation of latency critical services

Lowest latency packet forwarding to UEs



Moving virtual networks

Mission-critical services, e.g. in V2X or industrial applications

Central cloud based	> 50 ms latency
Mobile Edge LTE	≈ 10 ms
5G Edge	≈ 2,5 ms
5G D2D	≈ 1 ms

Vehicle2Infra trial on German motorway

Pioneer in Mobile Edge Computing

Vehicle2Infra live demos

ETSI ISG Chair

  public

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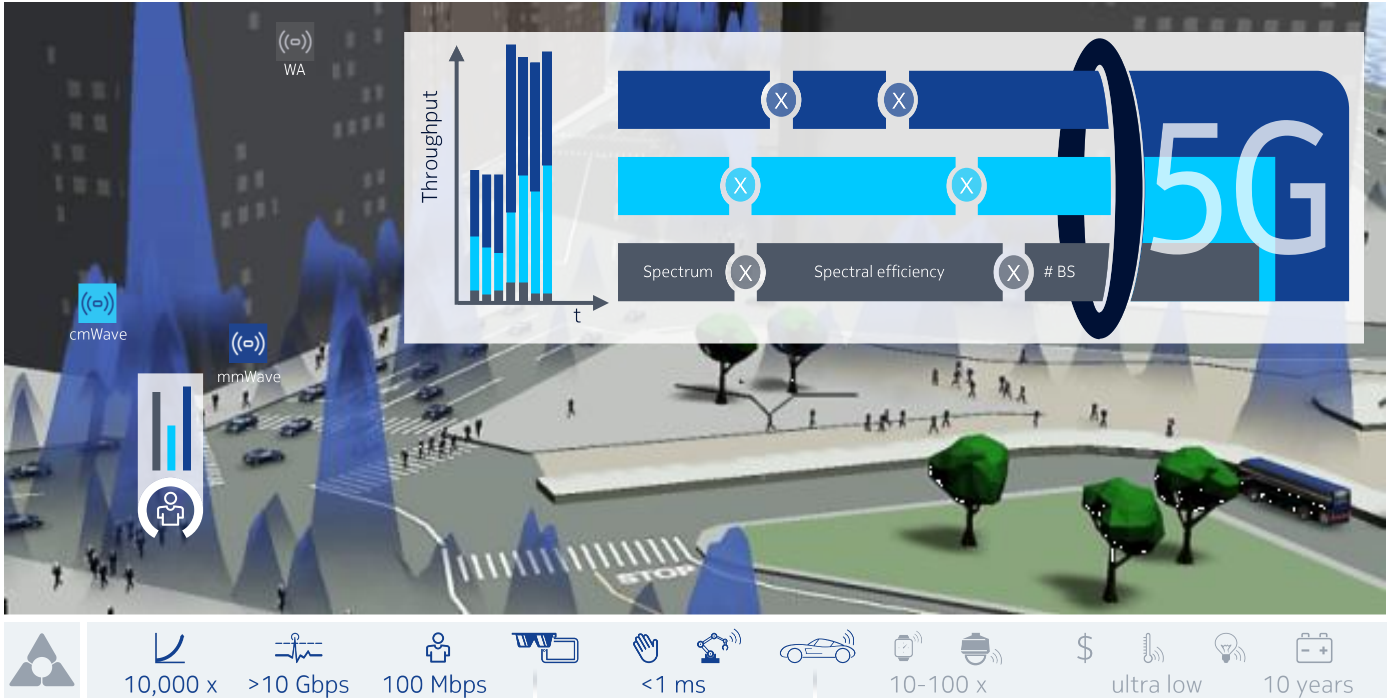
Multi-Connectivity | Perception of infinite capacity

Multiple radio technologies collaborating as one system



Extreme mobility robustness and ultra reliability

>100 Mbps anywhere

~ 3X burst throughput*

4G/5G real-time radio resource management know how built on demonstrator

*in example area, 50% load

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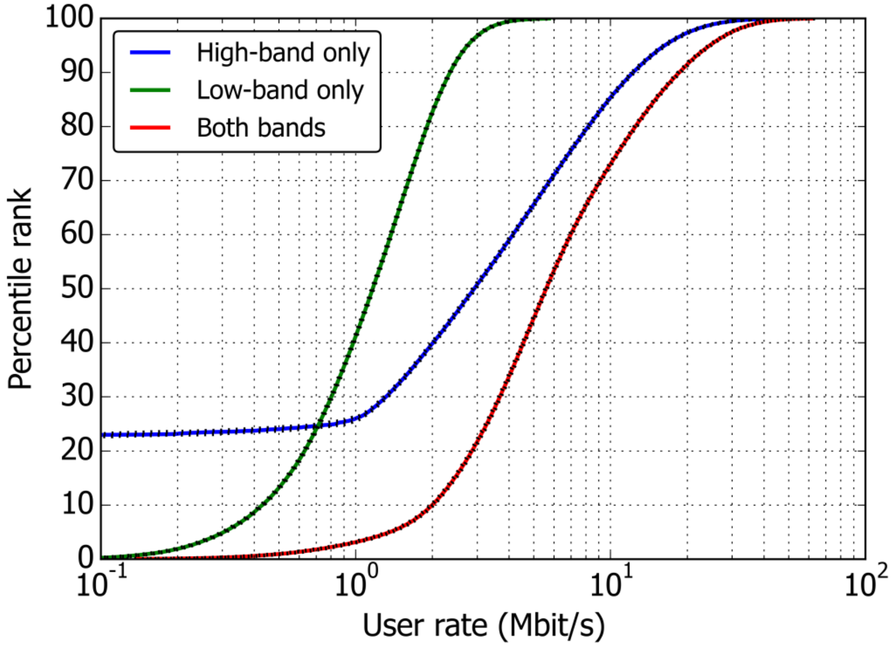
Multi-connectivity Gains

Opportunistically allowing mmwave to complement low band transmissions.



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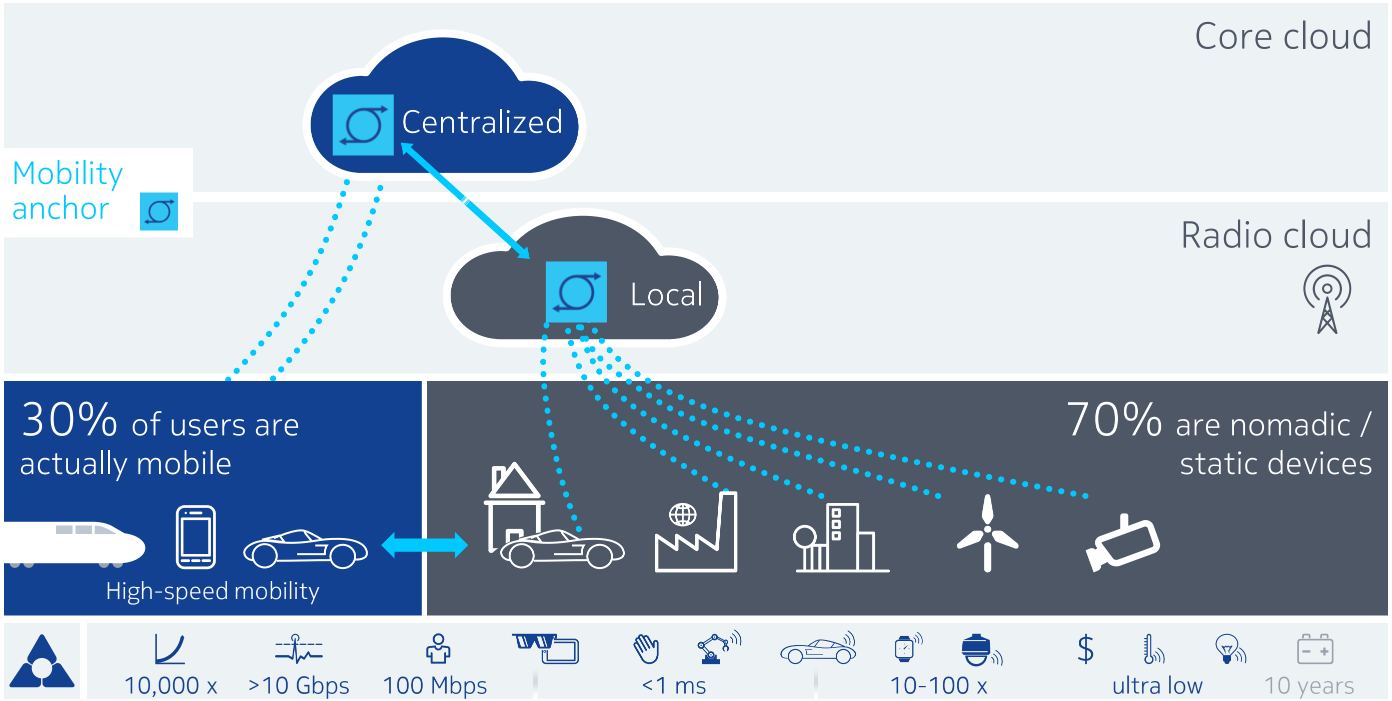
Mobility on demand | Highly efficient resource utilization
TCO optimized use of network resources



Less traffic backhauling to centralized cloud

TCO optimization

Best per service flexibility

Reduce core network resources

  public

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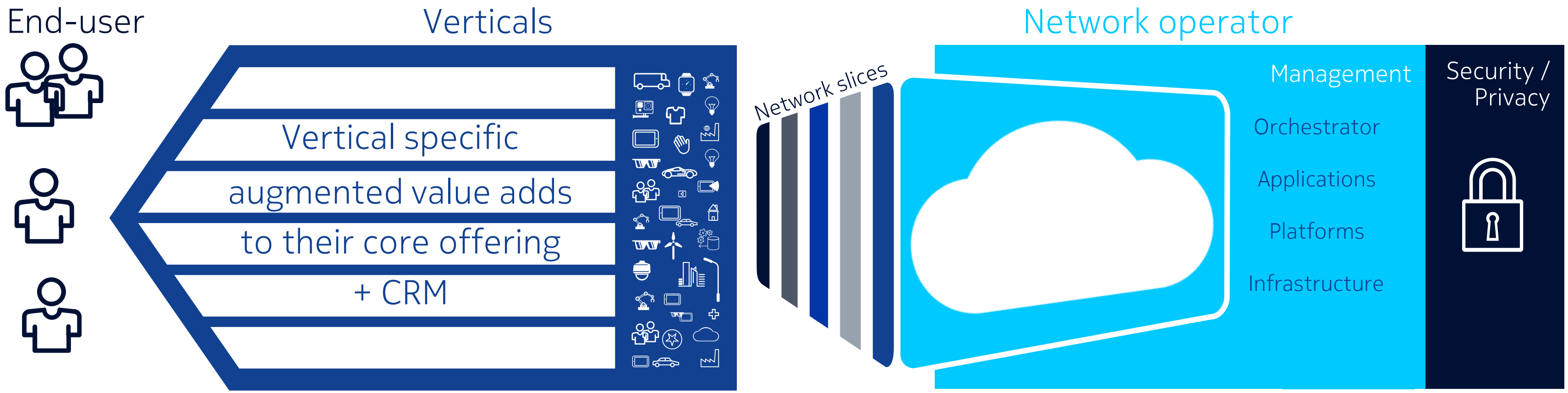
Network slicing

Help different industries to transform



KEY ENABLERS

- Slicing
- Dynamic Experience Management
- Any-to-any connectivity
- Low latency
- Slim radio for IoT

Network as a Service

Safety & Security | Mobile living | Utility & Energy | Traffic Mgmt. | Auto-motive | Health | Communi-cation | Logistics

Tailored vertical XaaS solutions

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Key milestones on the road to 5G – What's next?

2014

1st Brooklyn 5G Summit

- First 5G MWC showcase
- NTT DoCoMo cooperation
- MoU with CMCC/CMRI

2015

5G Radio demos

- 5G PPP projects started
- Positive outcome at WRC2015
- 3GPP standardization kicked off for 5G

2016

5G System demos

- 5G PPP projects in full swing
- 5G standardization on channel model, requirements and technology option selection

2017

Single RAN 5G System

- 3GPP 5G work in full progress
- IMT2020 evaluation process in ITU-R

2018

Pre standardized trials

- 5G phase 1 specs ready
- WRC2019 preparation underway
- Technology trials with key customers

2019

Pre commercial trials

- WRC19 outcome clear with new bands for IMT
- 5G phase 2 specs ready
- ITU-R process nearing completion

2020

Commercial network opened DOCOMO

- Research on "6G" starts

+ Details

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